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FINAL REPORT

VOLUME II - GROUND SEGMENT

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SPACE SYSTEMS DIVISION

GENERAL ELECTRIC

26 OCTOBER 1984

LANDSAT-D PROGRAM

FINAL REPORT

VOLUME II - GROUND SEGMENT

PREPARED FOR:

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

GODDARD SPACE FLIGHT CENTER

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This Landsat-D Ground Segment Final Report is the second volume of the Landsat-D Program Final Report. The first volume, Mission Systems and Flight Segment, was distributed separately, and consisted of the first five (5) sections of the report.

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SECTION 6

GROUND SEGMENT

Raw digital data, as received from the Landsat spacecraft, cannot generate images that meet specifications. Radiometric corrections must be made to compensate for aging and for differences in sensitivity among the instrument sensors. Geometric corrections must be made to compensate for off-nadir look angle, and to calculate spacecraft drift from its prescribed path. Corrections must be made for look-angle jitter caused by vibrations induced by spacecraft equipment. Annotations must be calculated and added. It is the function of the Ground Segment to perform these adjustments to the output products.

The major components of the Landsat Ground Segment and their functions are shown in Figure 6.0-1, and a simplified data flow diagram is shown in Figure 6.0-2. As initially proposed, the Ground Segment schedule defined a hardware and software development effort ending in March 1981. It allowed three months for segment integration and systems tests, and three months for readiness demonstration and on-the-job training for the operations staff. Prior to a scheduled launch date of October 1981 for Landsat-D, each of the facilities - Operations Control Center, Data Management System and Landsat Assessment System - had its own procurement and development schedule to satisfy the overall Ground Segment requirements.

The Ground Segment is located in Building 28 at Goddard Space Flight Center, shown in Photo I.

Throughout 1979, the Ground Segment schedules were adjusted to reflect changing ground hardware delivery commitments without significant impact on segment delivery.

Late in 1979, it was recognized that the processing necessary to correct the spacecraft jitter environment would substantially increase the complexity of the thematic mapper processing algorithms. This complexity added to the difficulty of developing and programming the very high speed data processor and other special purpose hardware required for TM processing. Additionally,

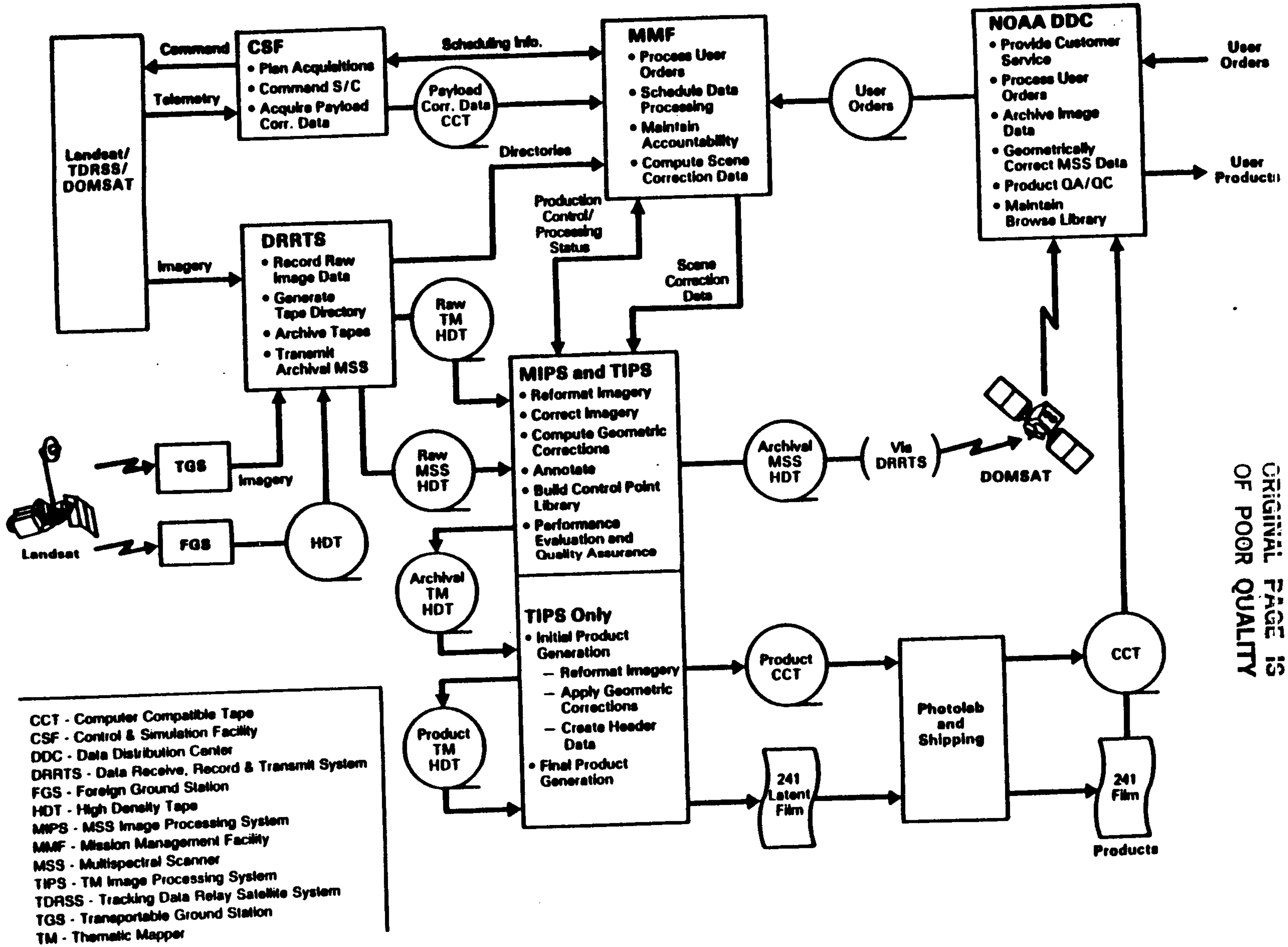

Figure 6.0-1. Major Components of the Landsat 4/5 Ground Segment and Their Functions

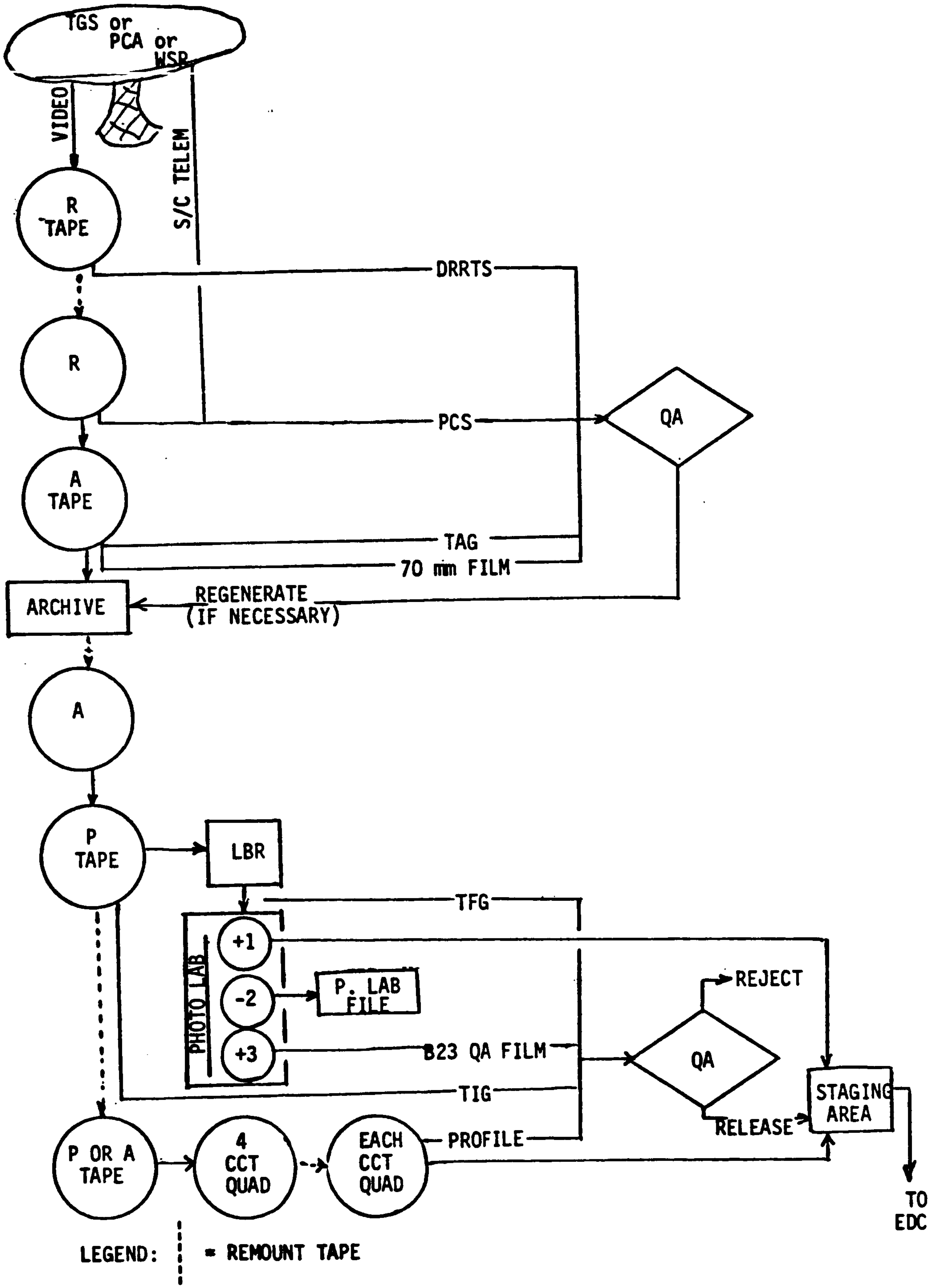

Figure 6.0-2. Simplified Data Flow Diagram

PHOTO I. GODDARD SPACE FLIGHT CENTER, BUILDING 28, HOUSING GROUND SEGMENT at this time, NASA was directed to plan the transition of Landsat-D operations to NOAA. These two factors led to the decision to separate the MSS and TM processing functions, using available hardware designs for the MSS Ground Segment and defining a separate development cycle for the TM Ground Segment.

Consideration of these issues were, in part, responsible for the program rebaseline activities that included an examination of the entire Ground Segment design and implementation concept. As a result of these activities in mid-1980, the image processing design concept was changed substantially and a new Ground Segment schedule was prepared. The Ground Segment was partitioned to provide separate MSS and TM Image Processing Systems with separate Mission Management Facilities and a common Data Receive, Record and Storage System. The key features of the revised schedule are outlined below.

The MSS Ground Segment development activities were physically separated from TM and off-the-shelf commercially available hardware was used. The control center and the MSS processing and production control development efforts were rescheduled to be complete by 30 April 1982 allowing a 90-day operational readiness period prior to a July 1982 launch.

Staffing for MSS operations began in October 1981, with training starting in February 1982. An MSS operational readiness period began on 1 May 1982 and ended with the launch of Landsat 4 on 16 July 1982. After launch there was a 90-day calibration period. Performance was demonstrated in October 1982. The turnover of the Ground Segment (including the CSF) to NOAA was scheduled for 31 January 1983 with training of the NOAA operations contractor beginning in November 1982.

A six-month effort to prepare the TM Ground Segment by 31 January 1984 for the launch of Landsat 5 in March 1984 was initiated in mid-1983. The effort consisted of testing software corrections in the image processing and production control systems and software enhancement and hardware additions in the control center to accommodate operation of both Landsat 4 and 5. A 90-day calibration period followed the launch of Landsat 5 on 1 March 1984.

Development of the TM Ground Segment was accelerated with the decision to launch Landsat 5. Specified processing capability was achieved by 30 April 1984 and demonstrated in October 1984. Full operational readiness was achieved and demonstrated in August 1984, resulting in the turnover to NOAA on August 31, 1984, of the fully operational TM Ground Segment.

The TM Ground Segment activities were redefined and rescheduled to complete 31 July 1983, which would mark the beginning of a one-year TM R&D period. August 1984 would mark the end of the TM R&D period and the beginning of a six month operational readiness period culminating with the turnover of a fully operational - at specified levels - TM Ground Segment to NOAA on 31 January 1985.

Because of the one-year period between the launch of Landsat-D (16 July 1982) and the completion of the TM Ground Segment development activities (31 July 1983), NASA made the decision to develop, separately, a single scene per day engineering capability for TM to provide early access and evaluation of TM data and TM instrument on-orbit performance immediately after launch of Landsat-D. This limited capability was dubbed the "Scrounge" system by NASA and did impact the TM Ground Segment design methodology and implementation schedule. These impacts are discussed later in the text.

The MSS Ground Segment, comprised of the CSF, DRRTS, MMF-M, MIPS, and TGS was turned over to NOAA on January 31, 1983. The TM Ground Segment, comprised of the MMF-T and the TIPS was turned over to NOAA on August 31, 1984. The Landsat-D Ground Segment is the largest and most complex facility of its kind ever constructed by GSFC. Both the MSS and TM systems met or exceeded all of their respective very stringent technical and operational performance requirements and were turned over to NOAA with no waivers or liens on capability or performance.

The delivered Ground Segment consists of multiple computer systems interconnected by electronic data links. It is a totally new system consisting of over 300 racks of equipment and over 1.4 million lines of software code. It includes nine Digital Equipment Corporation (DEC) VAX 11/780 computers, two DEC 20 computers, two PDP 11/34 computers, one PDP 11/23 computer, four AP-180V array processors, two FFP array processors, and two laser beam film recorders, plus a large assortment of high-density digital recorders, image displays and special purpose high speed image processing and communications hardware.

Photo II is a view of Ground Segment components under test at GE Lanham prior to installation in Building 28 at GSFC.

The Ground Segment is partitioned into four facilities: an Image Generation Facility (IGF), a Mission Management Facility (MMF), a Control and Simulation Facility (CSF) including the Transportable Ground Station (TGS), and the Landsat Assessment System (LAS).

Photo III shows the Ground Segment facilities.

Image Generation Facility

The Image Generation Facility consists of three subsystems: (1) Data Receive, Record, Transmit System (DRRTS), (2) MSS Image Processing System (MIPS), and (3) TM Image Processing System (TIPS).

The DRRTS records incoming MSS and TM data and transmits MSS archival data to the EROS Data Center in Sioux Falls, South Dakota. DRRTS utilizes high density digital recorders, controlled by a DEC PDP 11/34, for recording of data and generation of directories containing data type, quantity and quality and selected parameters for use during the geometric correction process. MSS and TM data can be received directly from the Transportable Ground Station or relayed via DOMSAT from the TDRSS ground station in White Sands, New Mexico, or MSS data only on high density tape from the NASA and Canadian ground stations and re-recorded within DRRTS for compatibility with the MSS Image Processing System (MIPS).

PHOTO II. GROUND SEGMENT COMPONENTS UNDER TEST AT GE-LANHAM

LANDSAT D GROUND SEGMENT

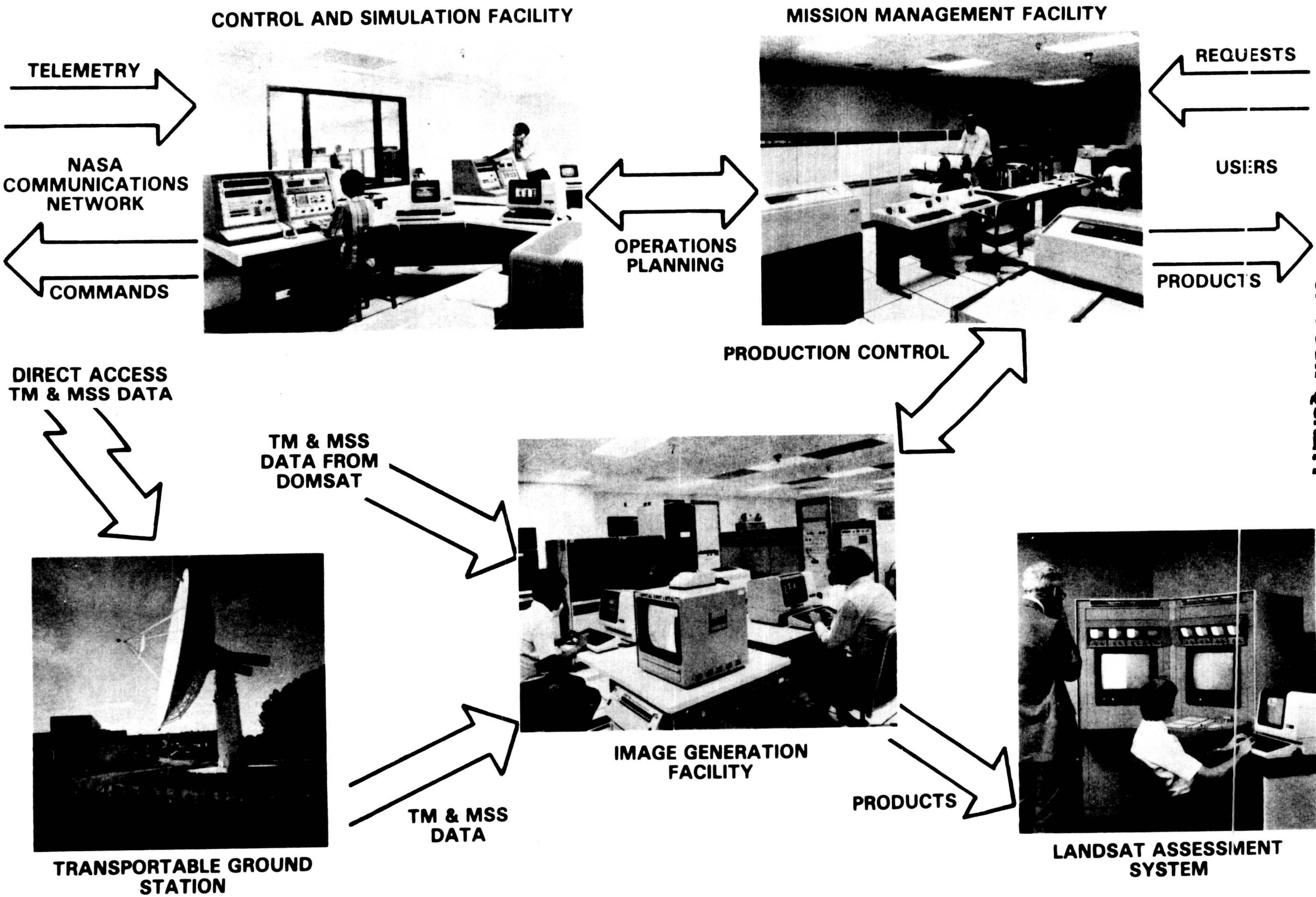

PHOTO III. GROUND SEGMENT FACILITIES

3

The MIPS consists of three identical processing strings (VAX 11/780 with a Floating Point Systems array processor) that produce partially processed MSS data, radiometrically corrected with geometric correction data included in the data format. The geometric correction data utilizes geodetic control points (identifiable Earth features) when available to register the data with respect to a map to within 0.5 pixel. The MIPS also has capabilities for in-depth online and offline performance evaluation and quality assessment. The MSS process flow is shown in Figure 6.0-3.

The TIPS consists of two identical processing strings (VAX 11/780 with a General Electric FFP array processor) that produce fully corrected film and CCT products. The geometric correction process uses geodetic control points when available to register the data to a map within 0.5 pixel. The TIPS also has capabilities for in-depth online and offline performance evaluation and quality assessment. The TIPS processing flow diagram is shown in Figure 6.0-4.

Mission Management Facility (MMF)

The MMF consists of a DEC 2050 computer and a DEC 2060 computer. The DEC 2050 is dedicated to MSS related functions and the DEC 2060 to TM related functions. Both systems are partitioned into four subsystems that perform user order processing, data base management, telemetry accounting and process control and report generation. User orders are received from the EROS Data Center, placed into the data base and used to schedule spacecraft acquisitions. Telemetry from these acquisitions is processed and forms the foundation for initiating process requests for the various steps of image processing. After the products are generated, the MMF initiates the requests for transmission of MSS data or shipment of TM products.

Control and Simulation Facility (CSF)

The CSF consists of four subsystems: Flight Operations, Performance Evaluation, Flight Scheduling, and Test and Simulation. The CSF utilizes three identical VAX 11/780 computers, linked together electronically, that can back one another up for redundancy.

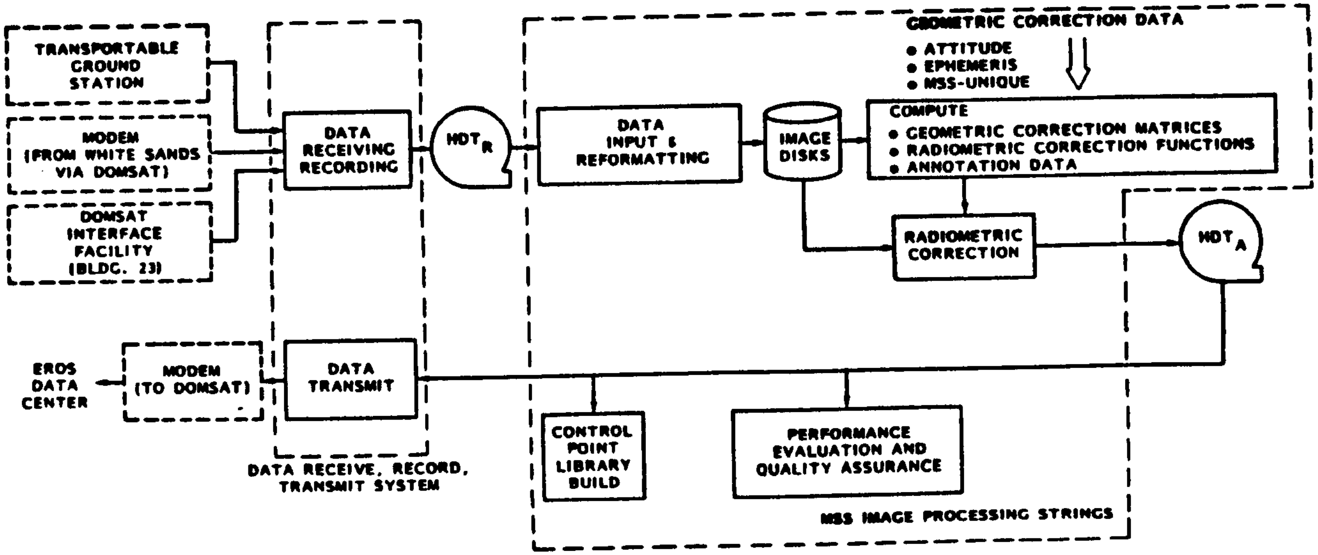

Figure 6.0-3. Multispectral Scanner Image Generation Process Flow

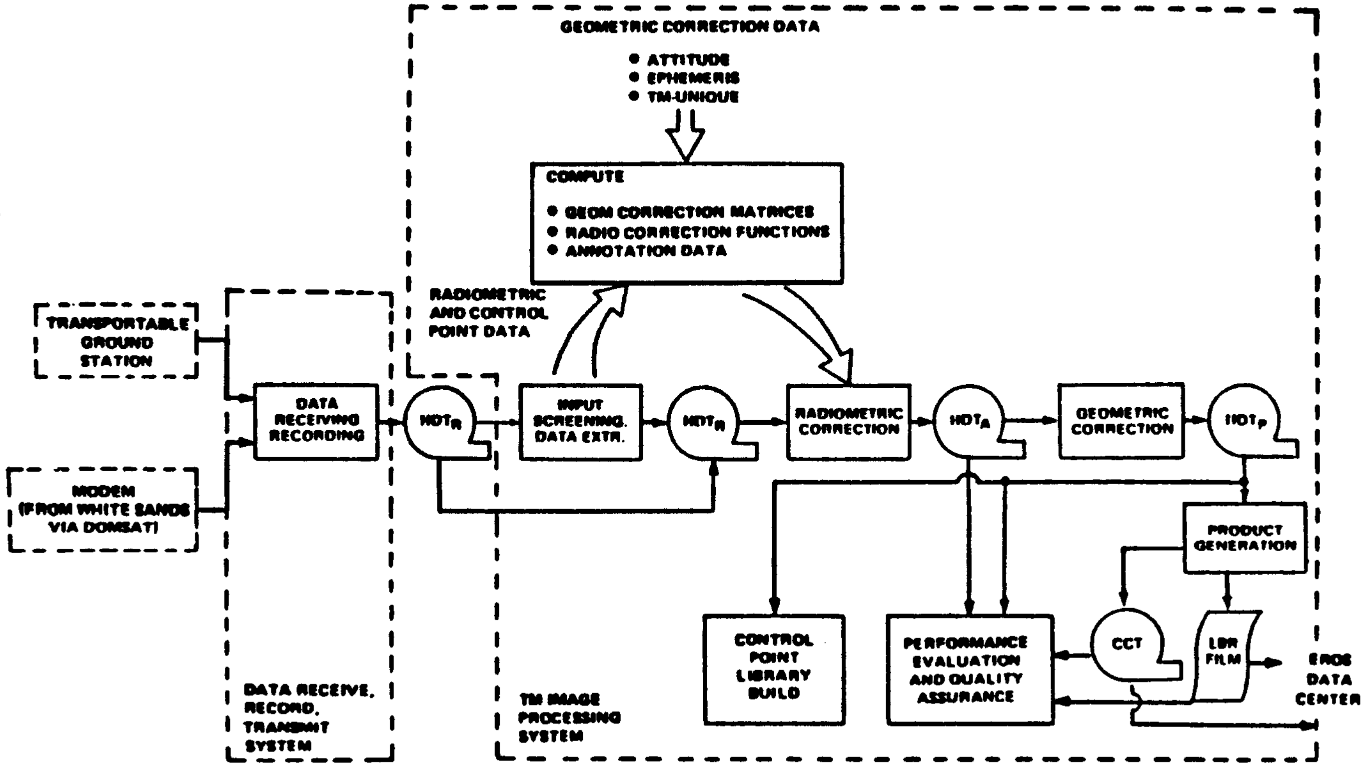

Figure 6.0-4. Thematic Mapper Image Generation Process Flow

The Flight Operations subsystem is the interface between the operations and the spacecraft. The subsystem processes telemetry, displays it to the operator and formats and transmits commands.

The Performance Evaluation subsystem provides the analysis and graphics tools to print, tabulate and plot telemetry points versus time.

The Flight Scheduling subsystem accepts candidate scene acquisitions from the MMF, processes these versus spacecraft and communication constraints, and generates a stored command load for the spacecraft.

The Test and Simulation subsystem provides a hardware replica of the onboard computer (OBC) and a software simulation for the remainder of the Landsat spacecraft. It is useful for rehearsing complicated procedures and validating both CSF and OBC software releases.

Transportable Ground Station

The Landsat-D Transportable Ground Station (TGS) is a receive-only system. It is capable of acquiring and tracking the Landsat-D series spacecraft and receiving the following spacecraft signals: X-band wideband data, S-band wideband data, and S-band narrowband telemetry data. The TGS demodulates and bit synchronizes received data. At its current GSFC location, wideband TM and MSS data are transmitted via cable modems to Building 28 for recording and further processing; narrowband telemetry and payload correction data are relayed to Building 28 via Nascom links in blocked data format. Antenna pointing information for acquisition and program track of the spacecraft is computed in the TGS from data provided by improved inter-range vector messages; upon acquisition of spacecraft signal, the system automatically goes into autotrack mode. The system includes a complete complement of test equipment for fault isolation and performance evaluation.

Landsat Assessment System

An R&D facility was provided consisting of data processing hardware and basic image processing software to serve as a resource for the investigation and development of new Earth resources management and analysis techniques using data from the MSS and TM sensors. The LAS includes standard general purpose automatic data processing equipment, an array processor, special purpose image analysis equipment and a complement of both standard and unique software. The facility is designed to assess the performance of the MSS and TM instruments, the corresponding ground processing systems and to support development of new applications for MSS and TM data in managing the Earth's resources.

EROS Data Center

The Department of the Interior's Earth Resources Observation Systems (EROS) Data Center in Sioux Falls, South Dakota, is the focal point for gathering user requests for MSS and TM data acquisition, MSS product generation and MSS and TM product distribution and archiving. The requests are consolidated and forwarded to the Mission Management Facility at Goddard Space Flight Center where they become the bases for scheduling operation of the instruments and communications links.

6.1 MISSION MANAGEMENT FACILITY (MMF)

The Mission Management Facility (MMF-M for MSS data; MMF-T for TM data) requirements were specified as part of the Data Management System (DMS) in the NASA specification. The major functions allocated to the MMF were:

a. User request processing
b. Image data production management
c. Management reporting
d. Data base management
e. Control point library management
f. Inventory control
g. Data transfer.

The user request processing function was partitioned into three categories:

a. Mission planning
b. Mission scheduling
c. Acquisition accounting.

Many of the requirements originally allocated to the mission planning and mission scheduling activities were reallocated to the Control and Simulation Facility (CSF) in an effort to reduce single-point-failure risks and to consolidate external interfaces related to Flight Segment operations into the CSF. The reallocated tasks associated with mission planning included:

a. Long- and short-term predicted ephemeris processing
b. Station contact processing
c. Planned candidate request filtering
d. Communication link notification.

The reallocated tasks associated with mission scheduling included:

a. Confirmed link support recording
b. Predicted cloud cover entry
c. Scheduled candidate request filtering.

Early in 1980, it was determined that the processing necessary to correct the spacecraft "jitter" would require a new subsystem to be added to the Ground Segment design. This Payload Correction Subsystem (PCS) was to be developed by Valley Forge analysis personnel and Lanham software personnel for implementation on the MMF host computer. The MMF system design was upgraded to accommodate PCS, resulting in a redefinition of some software modules, new software interfaces and upgrades of disk storage. At the same time, new MMF software modules were defined to maintain parameters required to support PCS and the band-to-band registration improvement in the TM image data processing algorithms.

In May of 1980, NASA released Revision B of the GSFC Specification for the Landsat-D System (GSFC-430-D-100B), which defined all of the changes that resulted from the rebaseline activities caused by the redefinition of the Landsat Program. This specification levied numerous new requirements on the Ground Segment that impacted the MMF. However, the requirement to provide MSS and TM processing separability led to a major change in the Mission Management Facility configuration, with the christening of two systems: the MMF-M for MSS processing and the MMF-T for TM processing.

Since the in-place design of the MMF included processing for both the MSS and TM data streams, the separation of sensor processing into two MMF systems resulted in a "cloning" of the MMF that would allow each system to be tuned to the unique specifications of its sensor's data processing. Likewise, each system could be adjusted to accommodate the unique processing requirements of the sensor's image processing system and payload correction subsystem. This separation led to a staggered development schedule with the MMF-M (the MSS system) being completed in December 1981 and the MMF-T (the TM system) in October 1982. The new Ground Segment configuration is depicted in Figure 6.1-1. The MMF-M served as the single interface point to the CSF and the DRRTS. TM data flowing between CSF/DRRTS and the MMF-T was routed through the MMF-M by way of a switchable mass storage unit and computer compatible tape. This effectively decoupled the MSS processing from the TM processing and

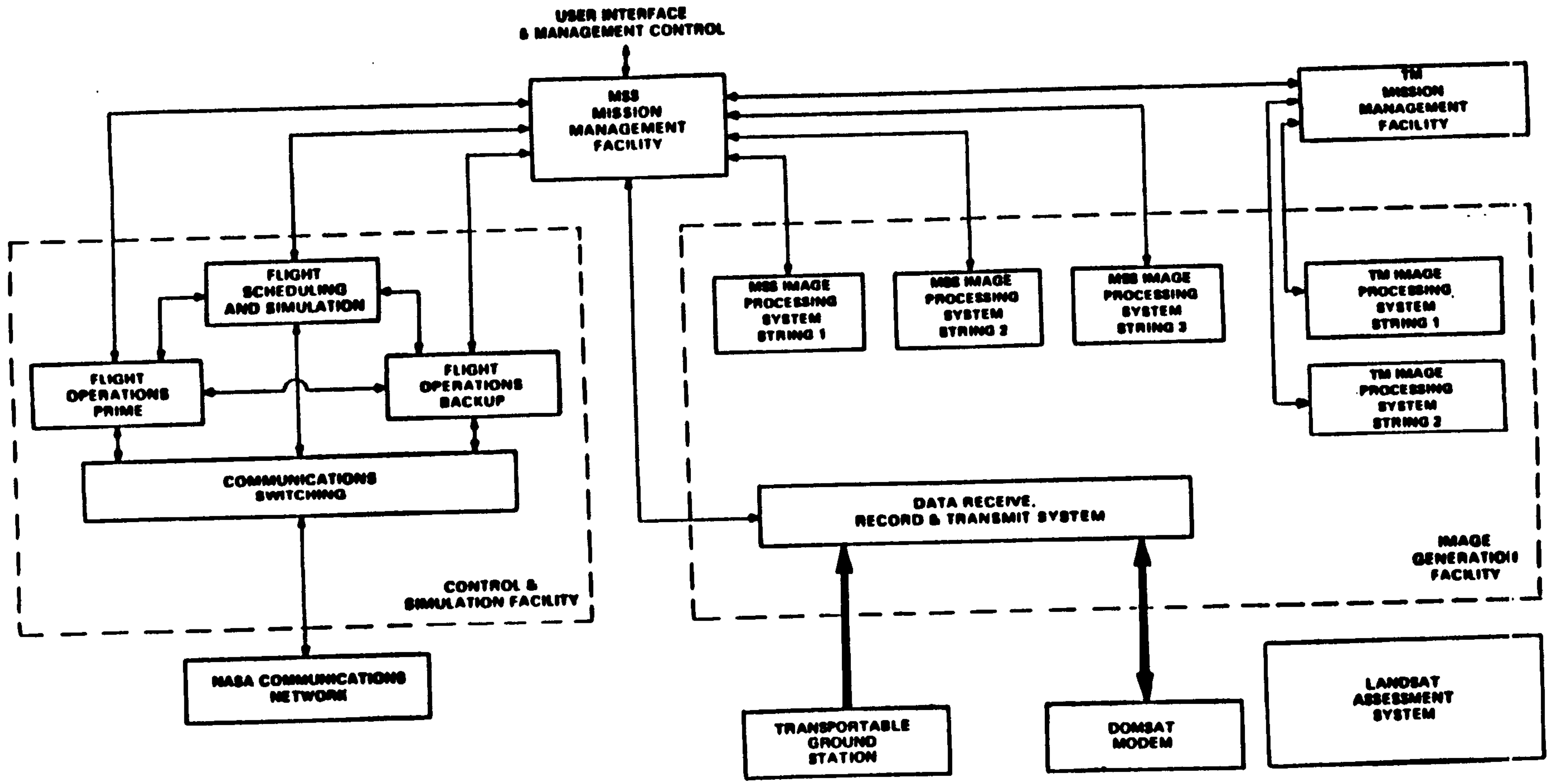

Figure 6.1-1. Ground Segment Configuration

allowed for the planned handover of the MSS processing elements of CSF, IGF and MMF to NOAA in January 1983. The TM-unique processing elements of the IGF and MMF were to remain under NASA control until a January 1985 final turnover to NOAA.

The MSS processing element was transferred to NOAA as planned on January 31, 1983. However, the TM processing element was transferred to NOAA ahead of schedule, on August 31, 1984.

6.1.1 HARDWARE CONFIGURATION DEVELOPMENT

The General Electric Company had proposed a Digital Equipment Corporation DEC System 10 as the central processor for the MMF. This system was upgraded to a DEC System 2050 in 1979. With the program rebaseline of mid-1980, the MSS and TM functions were separated into two similar systems. The MMF-M system was centered around the DEC System 2050 and the MMF-T system was centered around a second DEC System 20. A DEC System 2040 was considered, but the DEC System 2060 was eventually chosen due to the extra processing speed required to support payload correction processing. Both the MMF-M and MMF-T systems were equipped with off-the-shelf DEC peripherals, GE Terminet 300 printers attached to several KCRT stations, and Recognition Products OCR wands attached to the same KCRT stations. Both the MMF-M and MMF-T systems were eventually equipped with eight DEC model RP06 disk units and four DEC tape units capable of recording 800/1600/6250 bpi. The DEC 2050 system main memory final configuration was 512K 36-bit words, while the DEC 2060 system was upgraded to have 1024K 36-bit words of main memory.

Figure 6.1-2 is a block diagram of the MMF-M hardware configuration. Figure 6.1-3 is a block diagram of the MMF-T hardware configuration.

Photo IV shows the DEC 2050 System in the MMF.

6.1.2 SOFTWARE DEVELOPMENT

The MMF software system design had been substantially completed at the time of the program rebaseline in 1980. The software system design was not substantially modified as a result of the rebaseline, but was "cloned" into MSS and TM software systems. This partitioning of the MMF-M and MMF-T allowed

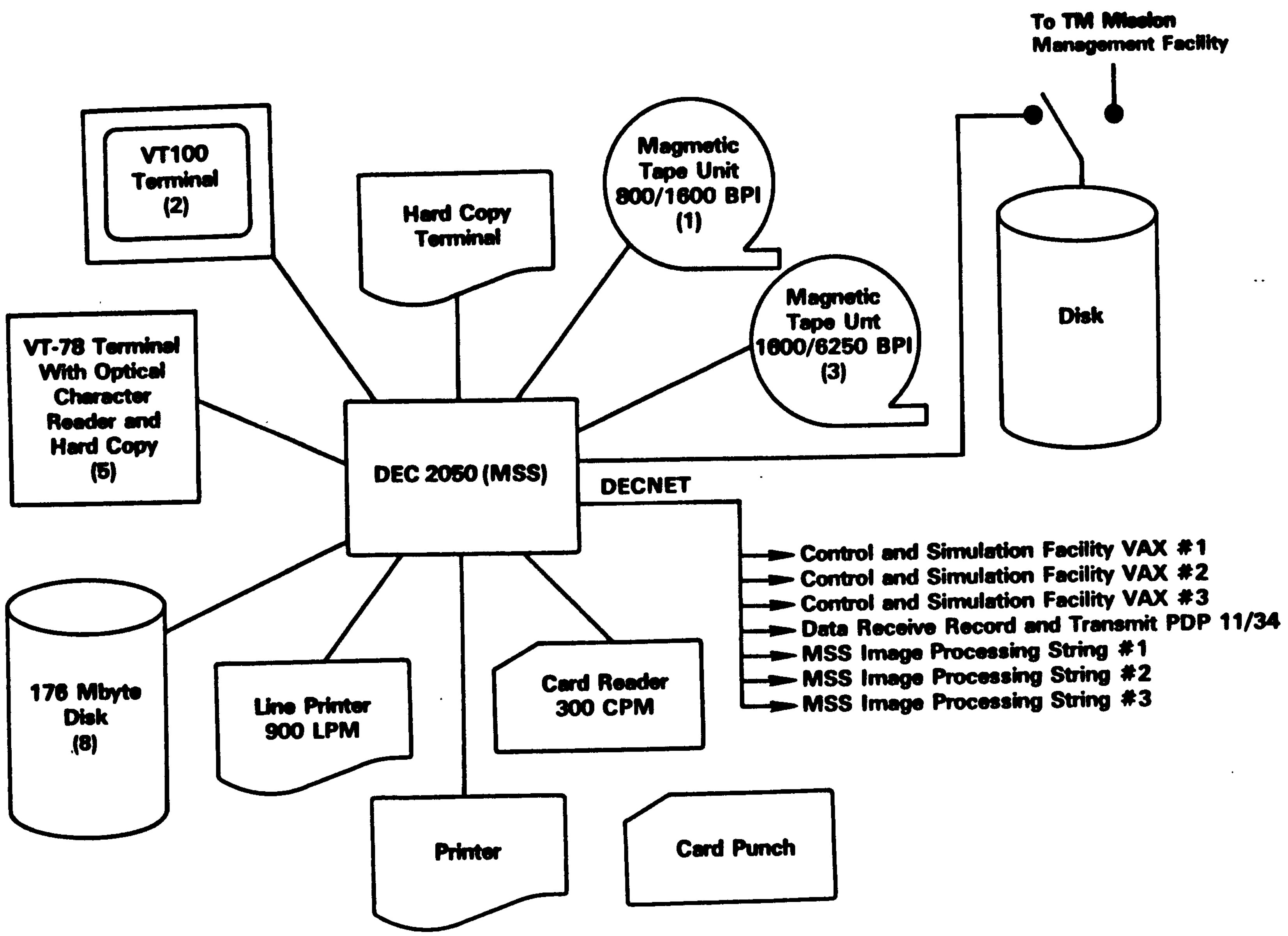

Figure 6.1-2. MMF-M Hardware Block Diagram

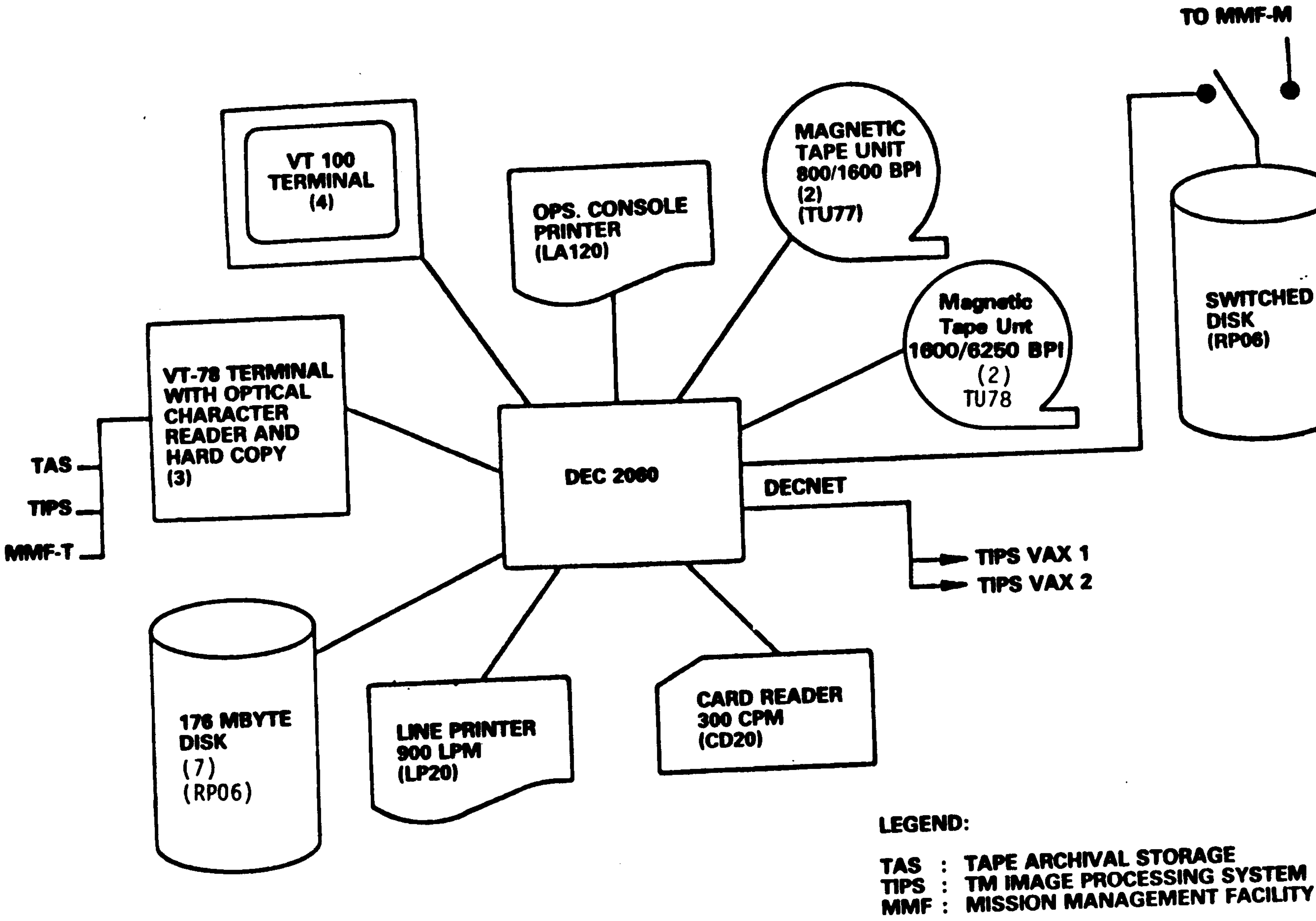

Figure 6.1-3. MMF-T Hardware Block Diagram

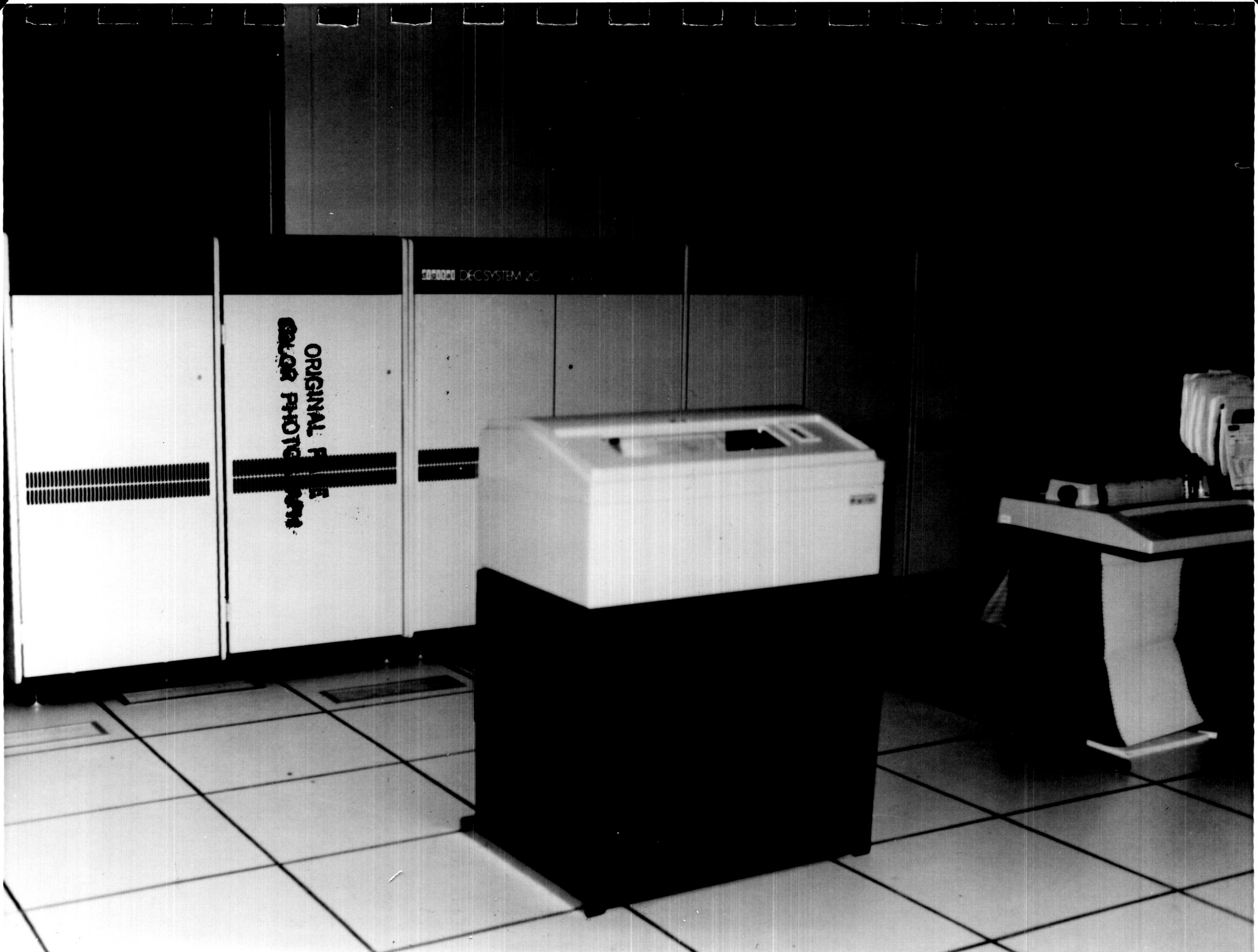

PHOTO IV. MMF SHOWING DEC 2050 SYSTEM

the software and data base designs to be tailored to meet the requirements of the respective instrument processing systems.

Each system was composed of four software subsystems:

a. Request Support Subsystem (RSS)
b. Flight Segment Management Subsystem (FMS)
c. Ground Segment Management Subsystem (GMS)
d. Data Base Administration Subsystem (DAS).

A block diagram of the MMF software subsystems and their major functions is shown in Figure 6.1-4.

The RSS was responsible for user request input, management reporting and inventory control. The FMS was responsible for processing user requests for spacecraft acquisitions, and for transfer of data to and from the Control and Simulation Facility. The GMS was responsible for image data production management, control point library management and transfer of data to and from the image processing systems. The DAS was responsible for data base management and transfer of data between the MMF-M and MMF-T systems.

The MMF-M and MMF-T applications software was developed using top-down software development methodologies that imposed structured design, design walk-throughs, pseudo code, structured code and code walk-throughs. The majority of the MMF-M and MMF-T software was written in COBOL, with some Fortran, MACRO assembly language code and Interactive Query Language, a high-order report generation language. The MMF-M application software consists of approximately 270,000 lines of code and the MMF-T application software consists of approximately 280,000 lines of code.

In addition to the applications software, both the MMF-M and the MMF-T employed operating system software, DECNET communication software and a CODASYL standard data base management system supplied by DEC.

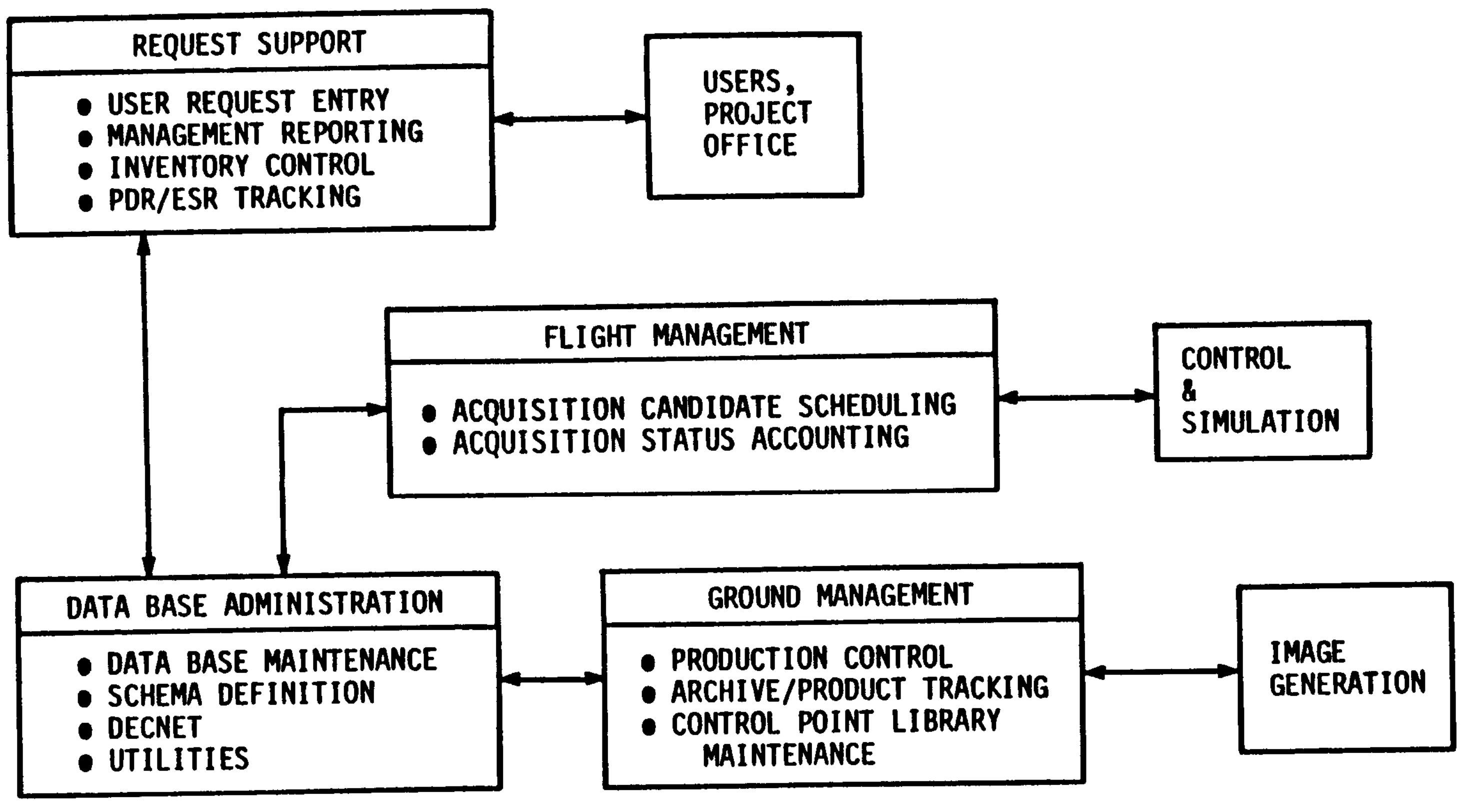

Figure 6.1-4. MMF Functional Overview By Subsystem

The MMF-M and MMF-T software systems employed a distributed functional approach in that each executable process performed a single function. Multiple executable processes could be invoked back-to-back in a runstream to accomplish a major processing step. These individual executable processes communicated with each other by way of status (control) information in the MMF data base so that subsystem boundaries effectively disappeared. The operator interface to the executable processes and runstreams was originally conceived to be by way of specialized command files. However, a more generic and flexible multi-layered menu interface was developed, offering selection of functionally related processes.

6.1.2.1 MSS Mission Management

6.1.2.1.1 Development

Several change notices affecting the MMF-M development were implemented prior to system operation. One of the new requirements levied by the NASA D-100B specification was the capability to process MSS data collected at GSTDN sites. This requirement was complementary to another new requirement, that of processing data collected at up to eight foreign sites. These two requirements affected all subsystems of the MMF-M, but each impact was small and implemented quickly.

A computer compatible tape interface to EROS Data Center (EDC) was also added to the MSS system. This was specified to be a two-way tape interface; MSS acquisition requests would be collected at EDC and periodically forwarded on an acquisition request order tape (AROT) to the MMF-M of the Ground Segment. The Ground Segment, specifically the MMF-M, would periodically generate an acquisition status information tape (ASIT) containing a snapshot of the user orders in the MMF-M data base and production status information for those user requests in process.

6.1.2.1.2 Operational System

The end-to-end MMF-M operations fall into the following categories:

a. Mission planning
b. Mission scheduling
c. Acquisition accounting
d. Archive generation support
e. Archive product verification support
f. Archive product dissemination support
g. Order closeout.

In addition to the end-to-end MMF-M operations, the following support activities are present in the MMF-M:

a. Performance evaluation product generation support
b. Control point library maintenance
c. Parameters maintenance
d. Management reporting
e. Inventory control
f. Data base verification and utilities.

6.1.2.1.3 Mission Planning

The MMF-M mission planning activities begin with the entry of user standing orders for acquisition into the MMF-M data base. On a regular basis the standing orders are intersected with the expected flight path of the spacecraft. These planned candidate requests are written in a sequential file, merged with the TM planned candidate request file and staged for transfer, via DECNET, to the CSF. The planned candidate request file contains a nominal seven days of candidate requests. The planned candidate file is used by CSF to perform resource planning for image acquisitions.

6.1.2.1.4 Mission Scheduling

The MMF-M mission scheduling activities are almost identical to the mission planning activities. The same user standing orders from the MMF-M data base are examined and a scheduled candidate request file is generated, merged with the TM scheduled candidate request file and staged for transfer, via DECNET, to the CSF. The scheduled candidate file contains a nominal 48 hours of candidate requests. The scheduled candidate file is used by CSF to perform resource scheduling and spacecraft commanding for image acquisitions.

6.1.2.1.5 Acquisition Accounting

After image acquisition is completed, the CSF returns three packages of information to the MMF-M: scheduled MSS and TM candidate request status, pre-processed selected MSS telemetry, and TM Payload Correction Data (PCD) directories. All three packages are transferred to the MMF-M via DECNET in the acquisition accounting activity. The actual PCD is forwarded to the MMF-T on magnetic tape. The MSS candidate information is segregated from the TM information and the MSS acquisition status is posted in the MMF-M data base. The TM candidate information is staged for transfer to the MMF-T. Scenes acquired for foreign site image processing are marked for closeout. Scenes acquired for image processing in the Landsat Ground Segment are forwarded to the archive generation support activity.

6.1.2.1.6 Archive Generation Support

The archive generation support activity encompasses a number of processes. First, the selected telemetry data is validated and staged for processing by the PCS. Once the PCS has completed the smoothing and attitude/ephemeris propagation, a telemetry directory is generated in the MMF-M data base. This directory is intersected with the list of scenes to be processed, which was supplied by the acquisition accounting activity. This intersection is then compared to recently received high density video tape directories to determine which scenes have video data present in the Ground Segment. Scenes to be processed that have sufficient telemetry and video data available are staged for processing by the PCS. Once the PCS has completed the generation of systematic correction data, the scene information is matched with selected control points from the control point library and placed on archive generation process requests. These requests are allocated to one of three MIPS strings for archive generation. After MIPS completes the archive generation task, the archive tape directory and associated feedback data are transferred, via

DECNET, from MIPS to the MMF-M, where they are validated; the process request is closed out, and an archival "main image" data base entry is generated.

6.1.2.1.7 Archive Product Verification Support

Each archive product high density tape generated by MIPS is scheduled by the MMF-M for QA evaluation in MIPS. This is done by way of a process request generated from manual inputs and the high density tape directory information from the MMF-M data base. The archive product verification process request is allocated to one of three MIPS strings, similar to the archive generation process request. Once the archive product verification task is complete, the MMF-M transfers, via DECNET, the associated feedback data for process request closure.

6.1.2.1.8 Archive Product Dissemination Support

Once the results of the archive product verification have been reviewed by operational quality assurance personnel, and release of the archive product is authorized, a process request for product dissemination is generated. This process request is routed to the DRRTS, which transmits the archival product data to the EROS Data Center. Once the transmission task is complete, the MMF-M transfers, via DECNET, the associated feedback data for process request closure. The MMF-M also generates a 9-track inventory tape containing pertinent information about the scenes transmitted. This inventory type is forwarded to another NASA facility for transmission to the EROS Data Center.

6.1.2.1.9 Order Closeout

Once the archive dissemination step has been completed, the corresponding user orders for acquisition and archive generation are updated to reflect successful completion. These standing orders remain open if the user requested more than one pass over the requested area in the user's specified time frame. Once the user's standing order is completely filled, or his specified time frame has expired, the order is closed. Standing orders for acquisition of data at foreign sites for foreign consumption are handled identically, except they undergo user order closeout processing immediately after the acquisition accounting step.

6.1.2.1.10 Performance Evaluation Product Generation Support

The support of the performance evaluation product generation (PEPG) function involves retrospective order entry, the generation of process requests for PEPG and accounting for this PEPG processing. By mid-1980, much of the PEPG support software functions had already been designed and built as TM product generation software. In order to keep development costs down, this design/implementation was preserved. The retrospective PEPG product orders are closed out via the user order closeout step.

6.1.2.1.11 Control Point Library Maintenance

The control point library maintenance function involves accepting unsolicited scene-oriented candidate control point lists, generating control point library build (CPLB) process requests for the candidates and depositing the generated control points in the control point library. The latter function also has the capability to deposit unsolicited control points from the Landsat 2/3 control point library.

6.1.2.1.12 Parameters Maintenance

Static and volatile parameters are maintained in the long- and short-term parameter files separately for MIPS and for PCS. The long-term files contain stable values, such as voluminous row-dependent data, including nominal systematic correction data. The short-term files contain values that would change periodically, such as pole-wander data. Parameter values are entered by terminal input or, for row dependent data, by sequential file. Each parameter file of each type applies to a given period of time for which imagery was acquired.

6.1.2.1.13 Management Reporting

The management reporting area contains four major subcategories:

a. Flight Segment reports
b. Ground management reports
c. Problem/defect reporting
d. Equipment service reporting.

The Flight Segment reports concentrate on potential acquisition candidate requests, actual candidate request status, spacecraft cycle acquisition statistics and acquisition maps. The ground management reports provide data on scenes in process in the Ground Segment, scenes in the archive on high density tapes, scenes on raw data tapes and image processing time lines statistics. The problem/defect report (PDR) processing system is built around a standalone data base of PDRs. This system includes entry/update and reporting software. Similarly, the equipment service report (ESR) processing system has its own data base, entry/update and reporting functions. Both the PDR and ESR systems were intended for development/operations management use, whereas the Flight Segment and ground management reports were intended for use by production control and operations management personnel.

6.1.2.1.14 Inventory Control

The inventory control system is built around its own data base and has its own entry/update software. It also has numerous reports for consumables and spares, such as suggested reorder list, overdue purchase orders list, master stock list, spares list, new purchase orders list and vendor code master list. The inventory control system maintains control over consumables and spares for both the MSS and TM portions of the Ground Segment.

6.1.2.1.15 Data Base Verification and Utilities

Data base utilities were developed to facilitate software development/integration, data base administration and operations. These data base unique functions include: common subroutines and copy files, data base load, data base unload, data base update and data base purge. The data base purge is most relevant to operations and basically removes old transient data from the data base. The data base update proved to be a valuable data base administrator's tool for operations, as well as a valuable development/integration tool. The data base verification functions are used for data base integrity checking. They include: chain chaser, area record summary and main image verifier.

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6.1.2.2 TM Mission Management

6.1.2.2.1 Development

After the mid-1980 rebaseline, several change notices affecting the MMF-T development were implemented prior to system operation. The first two change notices were implemented together, and comprised the Interim TM Data System (ITDS). The ITDS was partitioned into two subsystems, the TM Archiving Subsystem (TMAS) and the Accelerated Payload Correction Subsystem (APCS). The TMAS facilitated the TM data archiving period operations and the APCS, in conjunction with the TMAS, facilitated the Landsat TM early access period operations.

Other changes incorporated during the MMF-T system development were the AROT/ASIT interface to EDC. This interface included TM product information (requests and request status) as well as TM acquisition information. Also, the requirements to generate TM high density tape (HDT) inventory tapes (GHITs) for partially processed TM imagery (HDT-AT) and fully processed TM imagery (HDT-PT) were deleted from the program.

The final change notice required the capability to select for processing a subset of scenes from a single raw video tape, which had been archived via the TMAS. This function facilitated the TM R&D period operations. A summary of these periods and their processing requirements is shown in Table 6.1-1.

After the launch and activation of Landsat 5, the TM Ground Segment finally began operating in the manner that was designed for the operational "January 1985" system. Although some TM R&D tasks continued into this period, the processing scenario was one of processing all scenes acquired to archival tape (HDT-AT).

6.1.2.2.2 TM Data Archiving Period

Since the TM Ground Segment development was partitioned away from the MSS Ground Segment development, and since the TM Ground Segment development was

Table 6.1-1. TM Data Processing Periods Summary

PERIOD	FROM	TO	PRODUCTS	VOLUME (SCENES/DAY)
TM DATA ARCHIVING	16 JUL 82	FEB 83	TM LIBRARY TAPE	APPROX. 70
LANDSAT TM EARLY ACCESS SYSTEM	JULY 82	JULY 83	SYSTEMATIC CORRECTION DATA TAPE	1
TM R&D	1 AUG 83	6 SEP 83	HDT-AT HDT-PT 241 MM FILM CCT	3 3 3 1
	7 SEP 83	27 SEP 83	HDT-AT HDT-PT 241 MM FILM CCT	6 6 6 1
	28 SEP 83	18 OCT 83	HDT-AT HDT-PT 241 MM FILM CCT	9 9 9 2
	19 OCT 83	5 APR 84	HDT-AT HDT-PT 241 MM FILM CCT	12 12 12 2
LANDSAT 5 OPERATIONAL SYSTEM	6 APR 84	-	HDT-AT HDT-PT 241 MM FILM CCT	100 50 50 10

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scheduled for completion over a year after the launch of Landsat-D, the TMAS was developed. The TMAS performed the following functions:

a. Mission planning
b. Mission scheduling
c. Acquisition accounting
d. Raw data archiving
e. Management reporting.

The mission planning, mission scheduling and acquisition accounting functions of the TMAS were almost identical to the corresponding functions in the MMF-M and MMF-T.

The raw data archiving function created a library of correlated video tape directory information, PCD information and scene information from which the NASA Science Office could select scenes for subsequent product generation by way of the Landsat TM early access system and later, by the TIPS. The management reporting function was centered around a single report that itemized the contents of the raw data library. This reporting function was later upgraded to provide a commentary field that could be updated, on a scene or interval basis, with processing suitability information, such as data quality or cloud cover.

The TMAS was modified during the early operations phase to allow raw video tapes collected at Prince Albert, Canada, to be processed. These changes became a permanent part of the final "full TM" MMF-T system.

6.1.2.2.3 Landsat TM Early Access System Period

NASA had planned the development of a Landsat TM early access system to be comprised of parts of the Landsat Ground Segment and a NASA-developed Applications Data Development System (ADDS). This system, known as Scrounge, generated low-volume (one scene per day) engineering TM products using raw TM video data collected by DRRTS and TM Payload Correction Data (PCD) processed by CSF. The PCD was converted to Systematic Correction Data (SCD) by the Accelerated Payload Correction Subsystem (APCS) of the ITDS. The APCS was co-developed by Valley Forge systems engineering and MMF-T software/systems engineering personnel. The heart of the APCS was the engineering code prototype of the algorithms that would eventually be implemented as the operational TM Payload Correction Subsystem (PCS).

6.1.2.2.4 TM R&D Period

During the period of time that the TIPS system was operating at less than full capacity, the MMF-T provided process requests for selected scenes by way of a "bridge" between the ITDS raw data and the acquisition accounting activity of the "full TM" MMF-T system. This "bridge" software facilitated the gradual increase of production volume during the TM R&D period.

6.1.2.2.5 Operational System

The end-to-end MMF-T operations fall into the following categories:

a. Mission planning
b. Mission scheduling
c. Acquisition accounting
d. Archive generation support
e. Initial product generation support
f. Final product generation support
g. Archive/product verification support
h. Product dissemination support
i. Order closeout.

In addition to the end-to-end MMF-T operations, the following categories of support activities are present in the MMF-T:

a. Control point library maintenance
b. Parameters maintenance
c. Management reporting
d. Data base verification and utilities.

6.1.2.2.6 Mission Planning

The functions performed in the MMF-T mission planning activity are the same as those performed in the MMF-M system, except that the resultant planned candidate request file is also staged for transfer across the switchable disk to the MMF-M.

6.1.2.2.7 Mission Scheduling

The functions performed in the MMF-T mission scheduling activity are the same as those performed in the MMF-M system, except that the resultant scheduled candidate request file is also staged for transfer across the switchable disk to the MMF-M.

6.1.2.2.8 Acquisition Accounting

The MMF-T acquisition accounting activity begins with the transfer of the segregated TM candidate request status files and the TM PCD directory files across the switchable disk from the MMF-M. The TM candidate request status is posted in the MMF-T data base, in a process functionally equivalent to the MMF-M processing.

6.1.2.2.9 Archive Generation Support

Many of the processes of the MMF-M archive generation support activity were reworked for TM data processing. Only two new processes were added: the TM PCD directory ingest program and the TM systematic correction data (SCD) tape generation program. Control point selection is done on a wholesale primary/secondary control point chip basis, so the "selection" process is embedded in the control point library maintenance activity. In addition to these, the following unique requirements of TM were incorporated in the archive generation support processes: the TM PCD stream (32 Kbps) is in a different format than the selected data from the MSS telemetry (8 Kbps); the raw video tape directory data includes mirror scan correction data (MSCD); the TM archive generation process is interval oriented versus scene oriented. These, along with the accuracy requirements of the TM mission, drove the development of a totally new and more complex payload correction subsystem, which is embedded in the archive generation support activity.

6.1.2.2.10 Initial Product Support

The image generation process of generating a high density, fully processed initial product (HDT-PT) from the high density partially processed archive product (HDT-AT) does not exist in the MSS Ground Segment. The support activity consists of recording standing and retrospective requests for products, generating process requests for HDT-AT to HDT-PT processing and recording the HDT-PT directory/feedback information in the data base.

6.1.2.2.11 Final Product Generation Support

The final product generation activity is a continuation of the production control functions begun in the initial product generation step. This activity is identical to the MMF-M PEPG support activity, except that the TM product mix differs from the MSS PEPG product mix. Also, the order entry may be for standing orders or retrospective orders and is part of the initial product support activity.

6.1.2.2.12 Archive/Product Verification Support

This activity, similar to the MMF-M archive product verification support activity, controls the TIPS data quality function by generation of process requests and by processing the process request feedback. In addition to supporting HDT-AT verification, this activity supports HDT-PT, CCT-AT and CCT-PT verification.

6.1.2.2.13 Product Dissemination Support

This activity is functionally equivalent to the archive product dissemination support activity in the MMF-M. However, the products being disseminated are 241mm film roll masters and CCT-AT/CCT-PT original tape sets. This is accomplished by generation of paper process requests and shipping information that accompany the product to one of two shipping facilities (one for film, one for product CCTs). For film shipments, a roll inventory tape is generated that contains pertinent scene information. The inventory tape is shipped with the associated film rolls. Once shipment is complete, the annotated process request information is fed back into the MMF-T for process request closure.

6.1.2.2.14 Order Closeout

The order closeout activity for acquisition and archive generation orders takes place after the archive generation support activity and is identical to the order closeout activity in the MMF-M. For product orders, the order closeout occurs after product dissemination. Standing orders for products are handled the same as standing orders for acquisition. Retrospective product orders are immediately closed out after product dissemination.

6.1.2.2.15 Control Point Library Maintenance

The MMF-T control point maintenance differs from the MMF-M activity in that control points are selected and processed on sets of contiguous scenes. This activity also performs a selection function by identifying all "primary" control point chips for use in archive generation. The capability to update the control point directory data, including the selection flag, is also provided. The MMF-M capability to ingest Landsat 2/3 control points was not implemented in the MMF-T, since those missions did not carry the TM instrument.

6.1.2.2.16 Parameters Maintenance

Long- and short-term parameter files are generated for TIPS and PCS, as is the case in the MMF-M, but the content of the TM files differs greatly from the MSS files. The TIPS long-term file contains mostly radiometric correction parameters, Earth modeling data and other constants. The TIPS short-term parameter file contains active/substituted detector information, TIPS processing parameters and pole-wander data. The PCS long-term parameter file contains TM sensor/detector constants, telemetry calibration data and Earth modeling data. The PCS short-term parameter file contains only active/substituted detector information and pole-wander data.

The MMF-T has an additional capability to "modify" existing parameter files by updating a copy of the existing parameter file and marking the existing parameter file as inactive. The capability to install radiometric correction parameters by tape is provided, along with the standard terminal input mode.

6.1.2.2.17 Management Reporting

The management reporting area is almost identical to that of the MMF-M system. Only one additional report, the unprocessed TM PCD tape report, was developed. Most of the reports contain minor cosmetic changes to reflect the different characteristics of the TM sensor and the different aspects of the TM image processing system.

6.1.2.2.18 Data Base Verification and Utilities

As one might expect, the utility "building block" subroutines developed in the MMF-M were virtually unchanged for use in the MMF-T system. The data base load, unload and update functions were modified to be consistent with the MMF-T data base schema, which diverged from the MMF-M data base schema due to the unique TM sensor characteristics and TM image processing requirements. The data base purge process was substantially re-designed, due to the retrospective processing nature of Landsat 4 data. Substantial performance improvements were also realized as a result of the re-design. A read-only data base examine function was added to the MMF-T data base utilities area. The data base verification functions were also upgraded to be consistent with the MMF-T schema.

6.2 CONTROL AND SIMULATION FACILITY

The Control and Simulation Facility (CSF) provides for Ground Segment (GS) control over the Flight Segment (FS) operations. As the controlling element, it is responsible for FS health and safety as well as the proper scheduling and configuring of both flight and ground elements to permit payload data operations. To perform its task the CSF serves as the single location for FS telemetry processing and command generation (Figure 6.2-1). In addition, it supports external interfaces required for Landsat flight operations, such as orbital computation support and data communication link scheduling.

Several different factors acted as driving elements for the eventual design and development of the CSF. Table 6.2-1 provides a summary of a few of the more important inputs. The final results of these inputs are a CSF design that is much different from that of previous Landsat missions, and a development effort that was conducted simultaneously with newly evolving flight and ground elements.

The development schedule followed by the CSF reflected the continual major changes within the Landsat Program itself. As proposed in 1978, the CSF was envisioned as a modification of the earlier Landsat 1, 2 and 3 control center concepts with enhancements for performance improvements, especially in the area of hardware systems. This baseline was continually modified, in response to requirement redefinitions and system performance goals, and was never fully settled until the rebaseline period of late 1980. At that point the system hardware was finalized and the software design concept was developed. Although minor modifications continued to arise, the final system that currently supports Landsat 4 and 5 operations was formed directly from the program rebaseline concept. The final schedule followed by the CSF is shown in Figure 6.2-2.

The remaining paragraphs within this section provide a more detailed discussion of the respective hardware and software development efforts. Direct comparisons between the proposed and delivered systems are presented with additional details on what factors forced the changes. Despite the

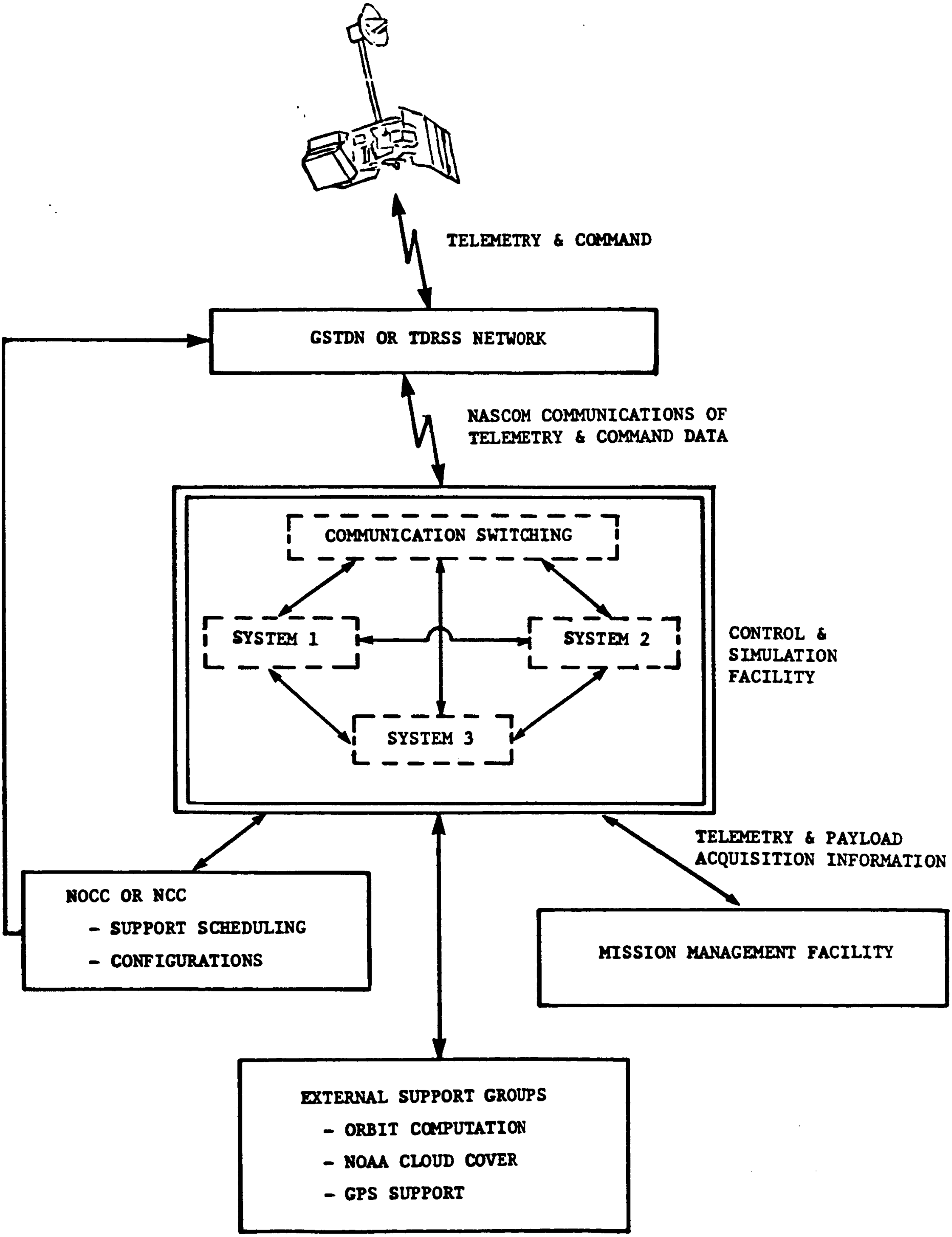

Figure 6.2-1. CSF Top-Level Baseline Concept

Table 6.2-1. Key Influences On CSF Design

DRIVING FACTOR	IMPACTS
Telemetry data formats & rates - 8 Kbps R/T, 32 Kbps OBC/PCD - 128/256 Kbps NBTR	Significant data rate and volume increase beyond 1 Kbps standard of 1970s Combined data rates of 136 (8 + 128) Kbps possible through TDRSS
Onboard computer and flight software	Allows for extended autonomous operation but at price of extensive critical software table generation Management and understanding of software critical to successful flight operations
Flight segment communication systems - multiple use of S-band channel - multiple paths for payload data	Mutually exclusive use of single channel by OBC, PCD and NBTR complicates operational scheduling Selection of appropriate transmission path(s) for payload data is receiving site(s) dependent - simultaneous multiple paths often required
TDRSS use for communication support	Management of steerable antenna aboard FS requires extensive planning to maintain correct pointing Scheduling requirements of TDRSS are very different from those of previous GSTDN systems
Simultaneous dual spacecraft operations	Required increased hardware capability and impacted software systems designs

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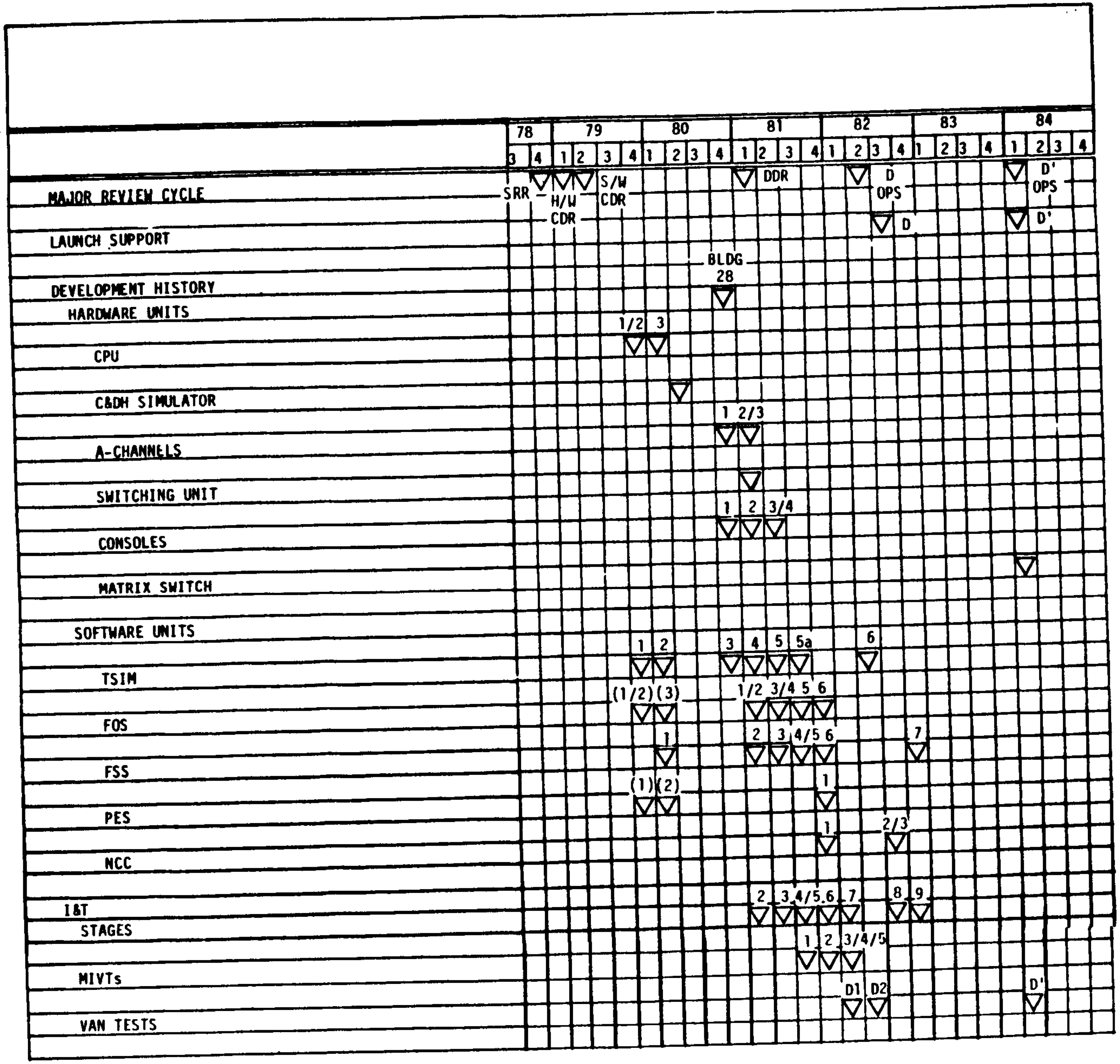

Figure 6.2-2. CSF Development History

difficulties caused by this continuous evolutionary system design, the CSF successfully provided its required functions at all of the mission critical points. The July 1982 Landsat 4 launch and the March 1984 Landsat 5 launch were both successfully supported, as have been their activation and continuing operational phases. In addition, the CSF has supported the first operational use of the Network Control Center (NCC) and the other Tracking and Data Relay Satellite System (TDRSS) elements.

6.2.1 HARDWARE CONFIGURATION

The originally proposed CSF hardware configuration was based on the development and operational concepts existing at that time. However, like most other Landsat-D systems, it went through numerous changes before a final configuration was formulated. This final design, while performing the same generic control center functions as originally proposed, was very different from that originally conceived.

Figure 6.2-3 shows the originally proposed CSF hardware system. The basic concept behind this design was to operate a single spacecraft with communications through the TDRSS network. Capture of the real-time telemetry was critical to allow image processing and thus redundant online systems were required. Advance planning and user order information was also required to ensure total accountability of acquisition since the concept was to acquire only "ordered" data. Thus, the third dedicated computer system for mission management.

The redundant flight operation systems utilized PDP 11/70 computers, each having 256 KB of memory, a single 176 MB disk drive and two STC 1600/6250 tape drive units. Output to hardcopy was available through either the dedicated Versatec printer/plotter device or to shared resources of a line printer, drum plotter, chart recorders or graphics terminal. Display consoles were switchable to either computer and utilized ISC 8051 color display terminals. External communications for telemetry, command, etc., were handled through the specially-built signal conditioning and switching unit (SC&SU). To allow

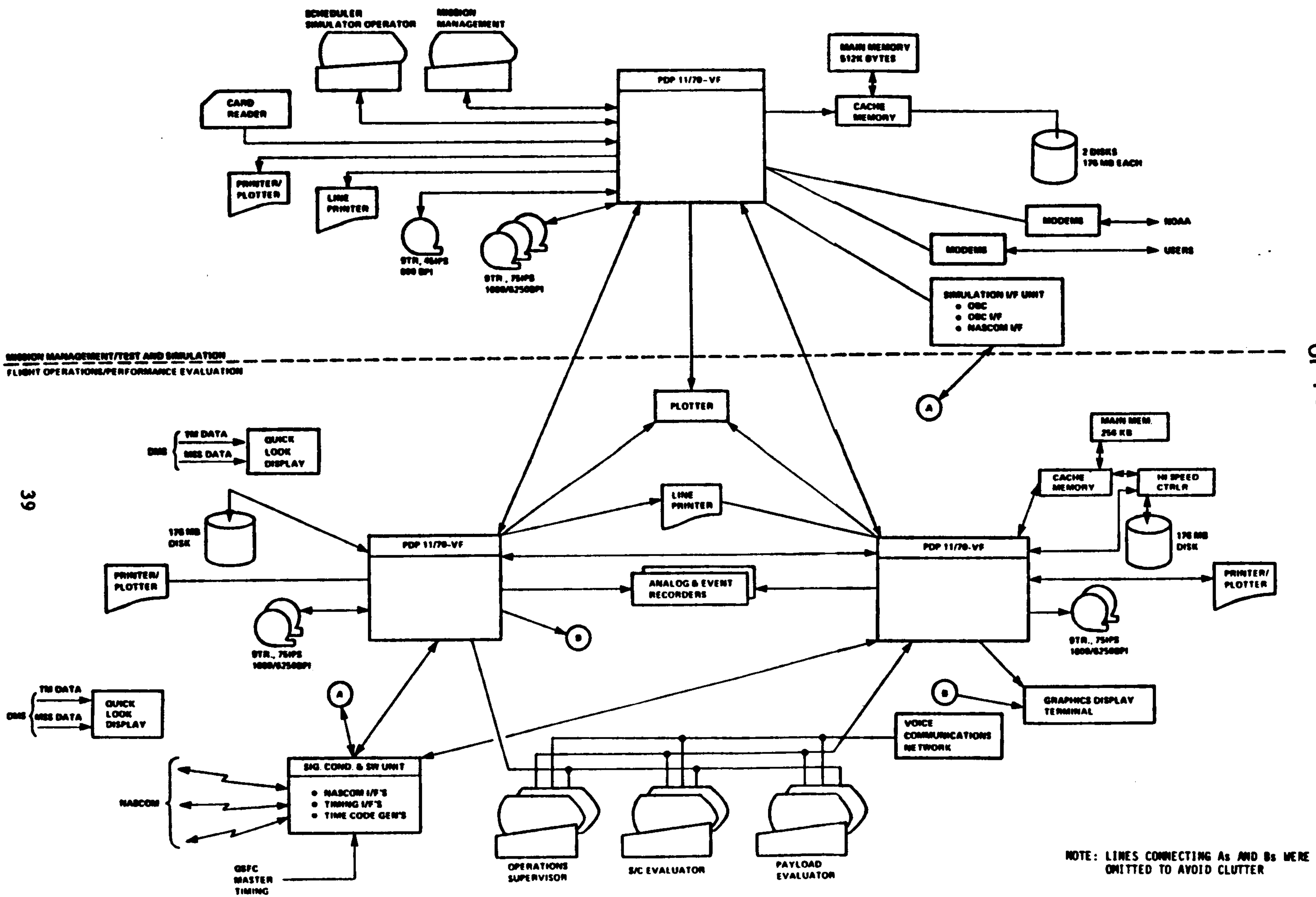

Figure 6.2-3. Proposed CSF Hardware Configuration

status evaluation of the payload instruments, a Quick Look Display, including decommutation devices for each sensor, was included.

The mission management computer consisted of a single PDP 11/70 with 512 KB of memory, two 176 MB disks and four tape drive units. Three units were high data STC devices, while a single 800 bpi unit was included to maintain external interface compatibility. Hardcopy output was through a dedicated Versatec unit, a dedicated line printer or the shared drum plotter. The expanded memory and disk drive systems were mandated by the user data required to support mission planning and processing control. To support user insight into their orders, a modem was provided to allow dial-in user inquiries.

Supported by the mission management computer, but utilized primarily for flight operations development support, was the simulation interface unit. This unit, in conjunction with software in the 11/70, provided a real-time simulation of the FS to supply realistic telemetry and command responses. Within the simulation unit was an actual ground version of the flight computer, capable of executing the flight code without change. Also included, to provide an interface to the flight computer, was a simplified command data handling system, similar to that aboard the spacecraft. This design was used to ensure that timing considerations were met. Utilizing the 11/70 to simulate the external world and spacecraft subsystems, and the simulation unit to execute flight code, a complete real-time simulation could be supported to provide inputs to the flight operation systems.

As a final note, all three mainframes were to be electronically interconnected for data file transfers.

Figure 6.2-4 shows the final configuration utilized to support Landsat 4, and provided to NOAA as part of the January 1983 turnover. Although a quick comparison shows that a three system ring concept was retained, very few of the hardware elements had not been revised. The system design uses three identical VAX 11/780 systems, each having 3 MB of memory; one dedicated and two shared 176 MB disks; and three dedicated tape units. The disks are

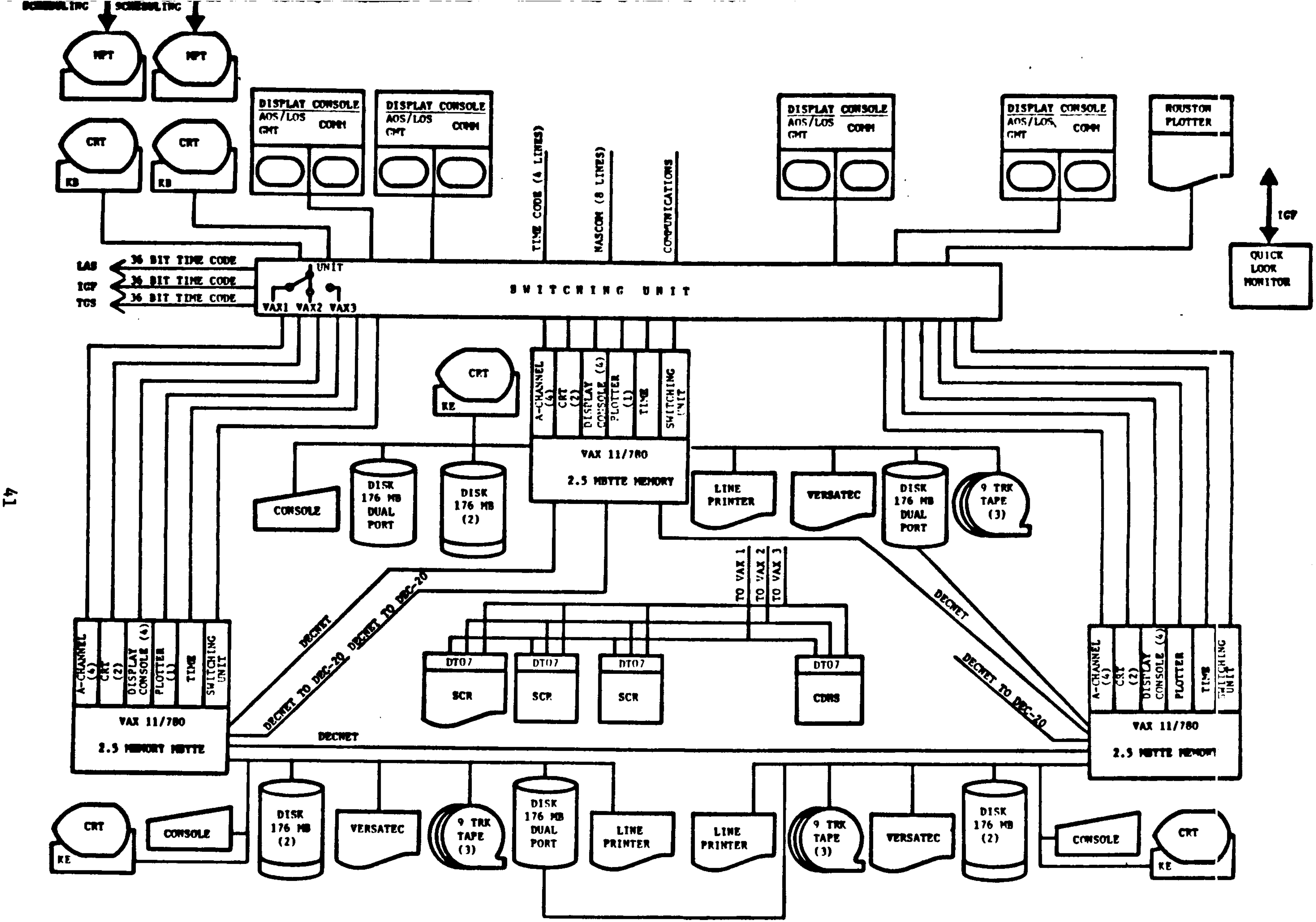

Figure 6.2-4. Final CSF Hardware Configuration

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arranged to nominally utilize three drives for each system, with the possibility of using up to five at any time. While the drives are dual-ported, thus easing switching, they will not support simultaneous access from two computers. Hardcopy output is available through dedicated Versatec units or line printers or through shared chart recorders or a drum plotter. Display consoles have increased by one, to a total of four, with the terminals being switched to monochrome VT100 units. Communication support through Nascom is now handled through the A-channel units, with the switching unit being downscoped to eliminate any data processing. Finally, the payload monitor was reduced in complexity by removing the respective decommutation hardware and providing a simple sensor data display scope.

Photo V is a view of the CSF System including the VAX 11/780.

The previous mission management system was reallocated, partially to the MMF (paragraph 6.1), and the remaining scheduling functions supportable by any available CSF VAX system.

One unit remaining fairly consistent was the simulator hardware. While the interface unit required adaptation to connect to the VAX, the concept of hardware/software simulation remained unchanged. Also unchanged was the electronic interface between systems to support data transfers. Now, however, an additional interface was supported to the MMF-M computer to permit data transfers for request scheduling and telemetry processing.

The following paragraphs provide further details into the specific history of each major hardware element and explain how the final approach was reached. Within each element a chronological presentation is made. Also, references back to Table 6.2-2 are made as appropriate.

6.2.1.1 Automatic Data Processing Equipment (ADPE)

As a common grouping, this refers to all of the standard computers and their peripherals, including the mainframes, memory units, disk drives, tape drives, printers and display units. Excluded from this section is the computer equipment within the simulator, as it is special purpose hardware.

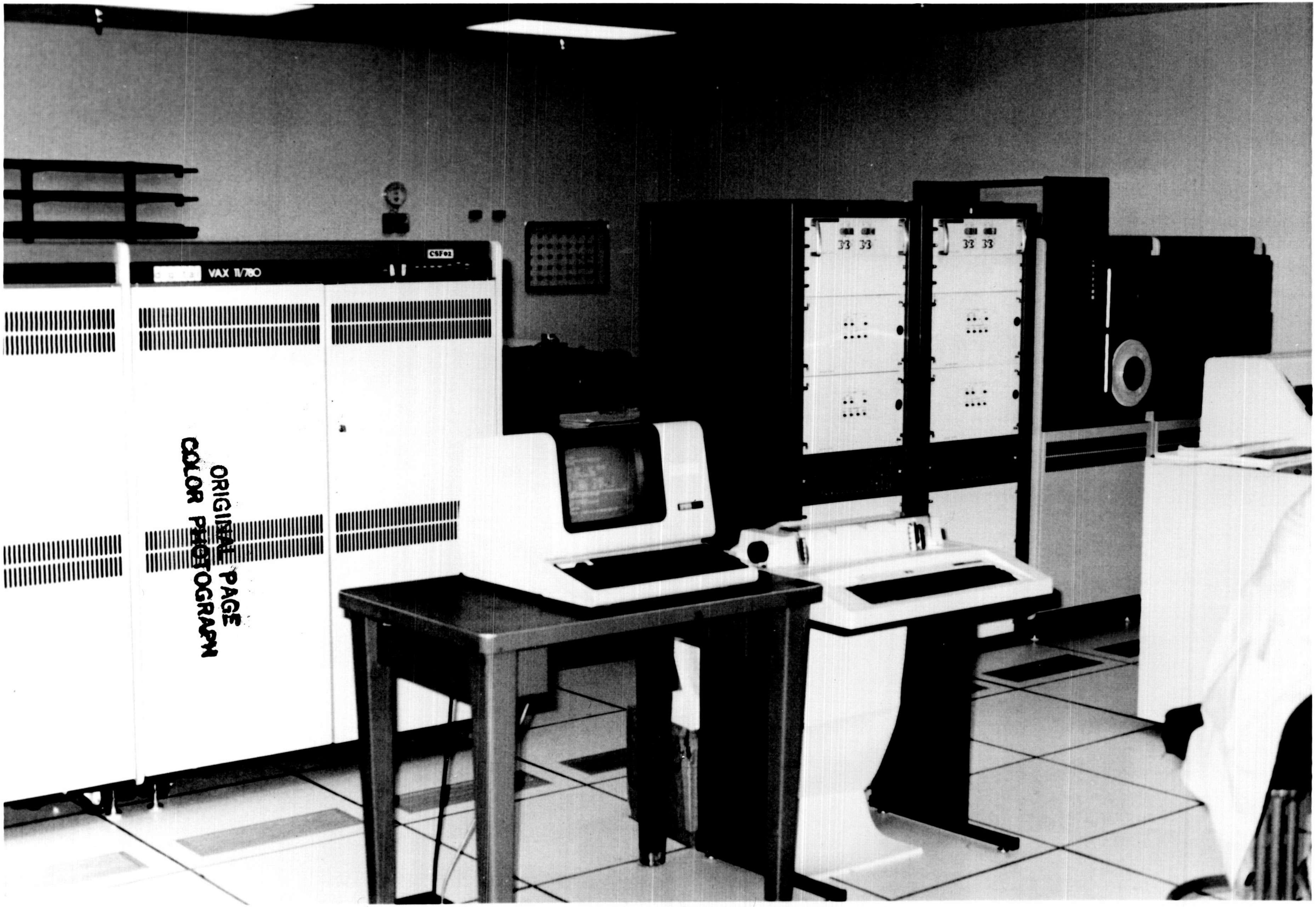

PHOTO V. CSF SYSTEM SHOWING VAX 11/780

The original computer selection of 11/70 mainframes was driven by the following factors:

a. Processing requirements
b. Availability of hardware and software
c. Commonality through the GS with DMS.

The memory and disk drives were selected for meeting the expected computation and data load of the single 8 Kbps telemetry rate. Also considered was the historical mission management data base, which required extra storage space for the one system. Where possible, due to relatively low usage rates, the equipment was shared to minimize excessive cost.

By late 1978/early 1979 the Data Management System (DMS) design, the other "half" of the GS, had been revised and their needs had outgrown the 11/70 computer. Also, a new DEC minicomputer, the 11/780, was introduced. To accommodate the DMS requirements a switch was made to the new 11/780 and, to maintain GS commonality, the CSF followed. This commonality was intended to save operating costs and, by upgrading systems, make available much new technology and increased performance. The decision to upgrade was completed by March 5, 1979, and presented as the baseline at the Conceptual Design Review.

The next major ADPE modifications were directed in December 1979 and January 1980. The former change was the addition, to both of the two online telemetry processing systems, of additional memory capacity and an additional disk drive. This change was made to accommodate processing of the PCD input required to correct thematic mapper image data. The latter change was made to correctly handle the newly added FS telemetry recorder data. The original concept of utilizing TDRSS real-time communication was being delayed by its late development. Narrowband recorders were incorporated within Landsat to support the GSTDN operations. Additional hardware requirements defined at this time included computer memory, another disk drive per system and a third tape drive for the two machines.

The final major hardware reconfiguration occurred with the rebaseline activities of September 1980. The program rebaseline was designed to support simultaneous dual spacecraft operations, which brought about several modifications. The first redesign was to provide three duplicate systems to provide real-time support to both spacecraft while retaining a "hot back-up" capability with the third string. Scheduling and non-real-time processing could be done either between passes on the prime machines or on the back-up computer.

A few months prior to Landsat 4 launch, a MIPS machine was configured (via system software parameters) to be used as a fourth CSF VAX. Software, testing and FS support personnel made extensive use of the fourth machine, both before and after the launch.

The original display system to be utilized in the CSF included 19-inch color display CRTs. The display software built for the CSF includes color parameter definition areas so that the operator could fully utilize the color capability in the CRTs for building displays. The selection of the color terminals in the CSF was based on terminal specifications versus requirements and cost. The terminals that were selected were manufactured by Industrial Data Terminals (IDT). The model selected for use in the CSF was one of IDT's newer designs and many problems resulted during the acceptance period. The problems with the terminals resulted in a return of the terminals to the manufacturer and the installation of DEC VT100 terminals as the primary CSF terminals. With a blend of purchasing and leasing, the number of terminals required for development, operations and system testing was achieved.

6.2.1.2 A-Channels

The baseline Landsat design provided for an interface to Nascom that consisted of three message-switched, full-duplex links carrying 4800 bit messages. These links would transmit telemetry and command data with real spacecraft data on one line and simulated data on another. The third line was to be used as a spare. The signal conditioning and switching unit (SC&SU) was designed to switch any one of these three duplex lines to any of the three VAX 11/780 computers. Block synchronization was to be performed by the SC&SU while frame synchronization was to be performed by the software in the VAXes. Figure 6.2-5 shows the original configuration of the Nascom-to-VAX interface.

In 1979, the interface between the networks and the Ground Segment changed from three full-duplex lines to five duplex and three simplex lines. These new lines now brought the configuration to eight input lines and five output lines. With the addition of the extra lines, and other new requirements in the interface, a redesigned Nascom interface was proposed. As shown in Figure 6.2-6, this system consists of an SC&SU with greater switching capability and a series of A-channels connected in series with the VAX computers.

The A-channels are part of a system developed by Ford Aerospace for use in Goddard Project Operations Control Centers (POCCs). This system, called the Telemetry and Command (TAC) computer, is based on a DEC PDP 11/34 computer. Due to the uniqueness of the Landsat 4 requirements, the design of the TAC was modified to include only the A-channels for Landsat. The Ford design was chosen to: 1) take advantage of the standardized Nascom interface design, and 2) to utilize the software already developed. The processing to be done by the PDP 11/34 in the TAC would be done by the VAXes in the CSF. Table 6.2-2 shows the basic capabilities included in the A-channels.

The CSF system was developed so that control and set up parameters for the A-channels could be entered by a controller in the CSF Mission Operations Room (MOR). Parameters that are unique to specific stations or operations could be stored in catalogs and recalled when needed. The front panel of the A-channels contained status indicator lights. These lights showed data block presence and data lock status through illumination of red, yellow and green lights. Prior to the launch of Landsat 4, these indications were remoted to a panel in the MOR. They provided the operations staff with a quick and accurate indication of the incoming and outgoing data links.

A view of the Spacecraft Command Console is shown in Photo VI.

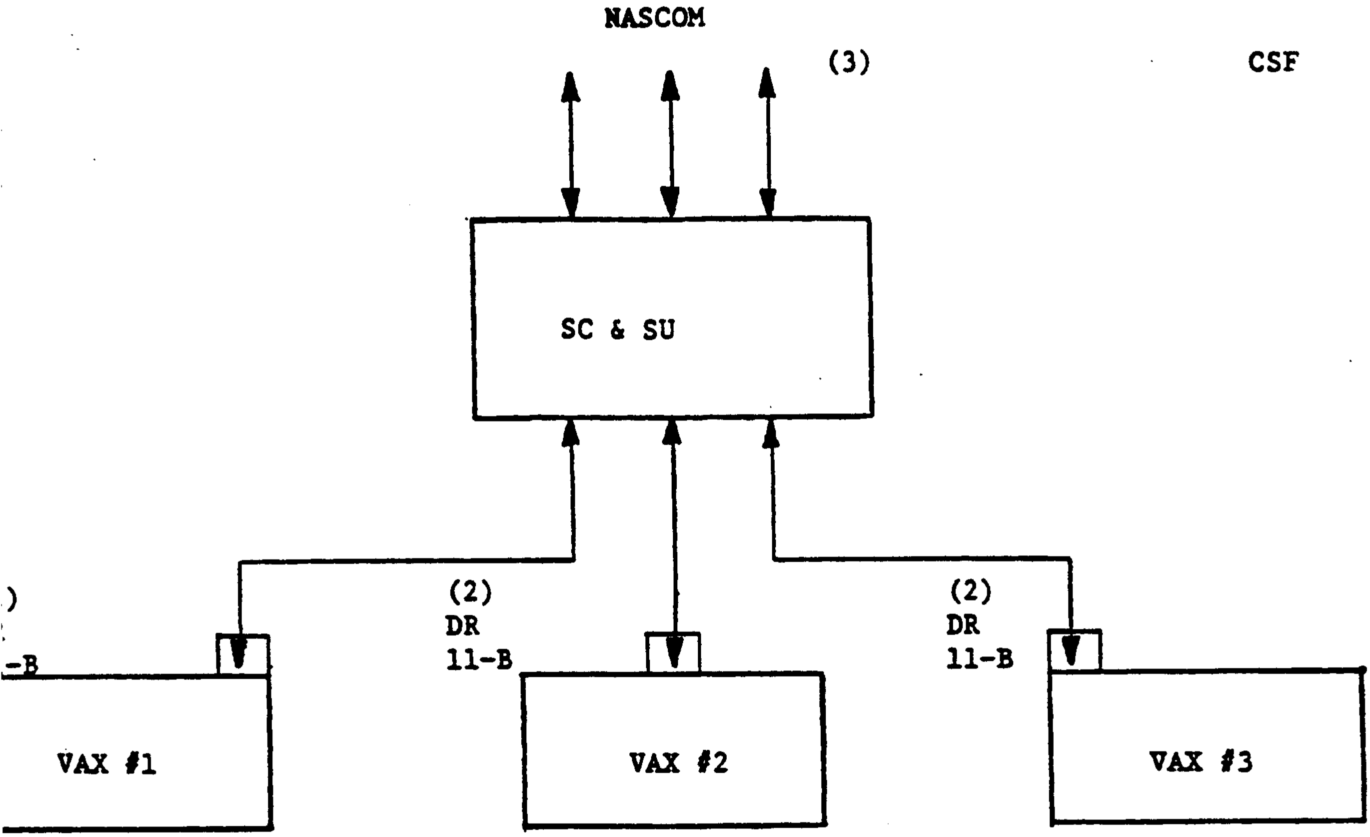

Figure 6.2-5. Baseline CSF Nascom Interface

NASCOM

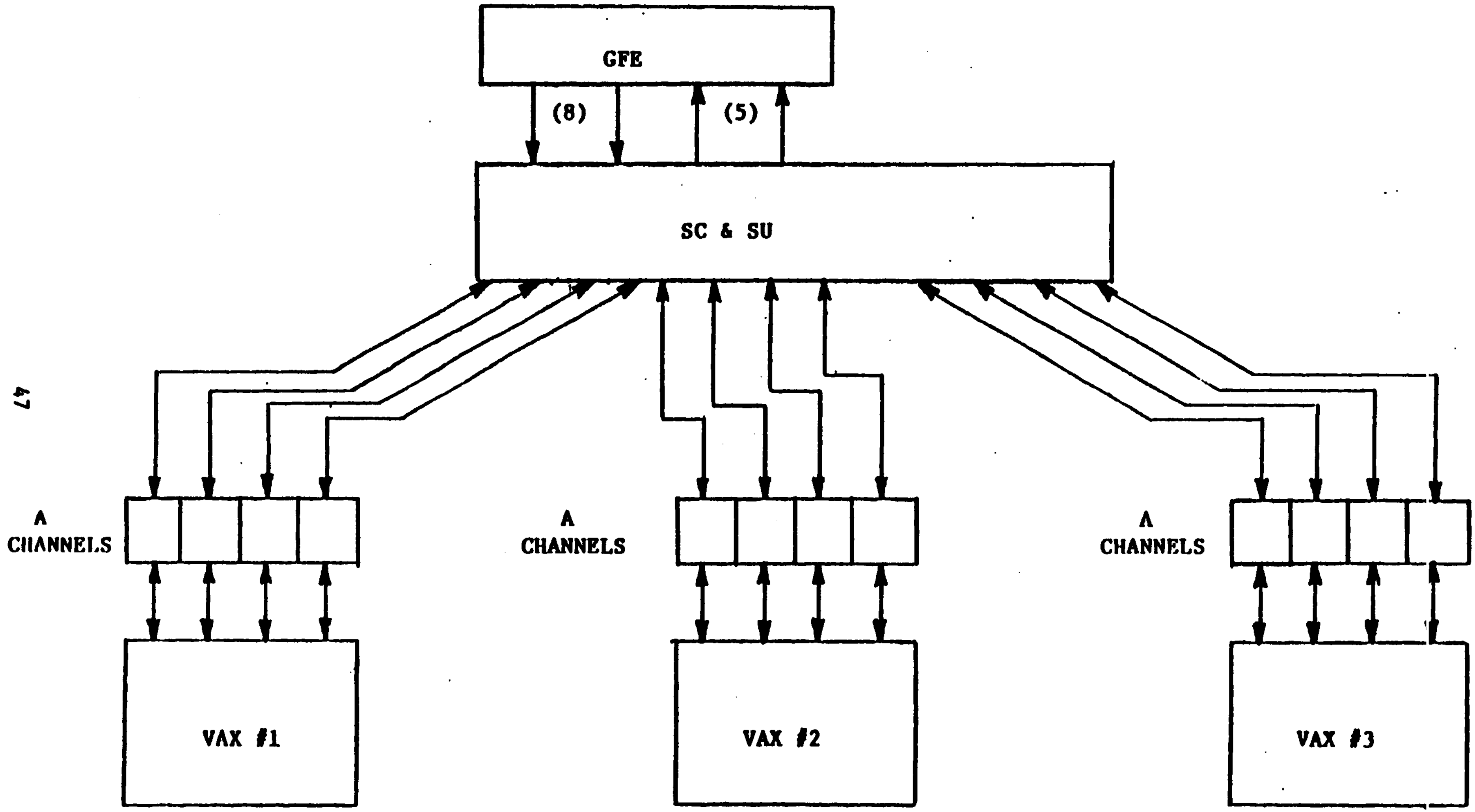

Figure 6.2-6. Rebaseline Nascom Interface

Table 6.2-2. NIF Capabilities Summary

- A-CHANNELS - FOUR PER COMPUTER - ONE PER NASCOM LINE
  - DETECTS NASCOM BLOCKS (INCOMING)
  - ERROR CHECKS NASCOM BLOCKS (INCOMING)
  - MINOR FRAME SYNCHRONIZATION (INCOMING)
  - CORRELATES MINOR FRAME SYNC/GROUND RECEIVED TIME (INCOMING)
  - DISCARDS UNWANTED BLOCKS (INCOMING)
  - TRANSFERS NON-TELEMETRY BLOCKS, FRAME SYNCHRONIZED TELEMETRY, AND STATUS RESULTS TO COMPUTER (INCOMING)
  - METERS BLOCKS (OUTGOING)
  - ADDS ERROR DETECTION CODES TO BLOCKS (OUTGOING)
  - CONVERTS DATA PCM CODE FROM NRZ-L TO NRZ-M (OUTGOING)

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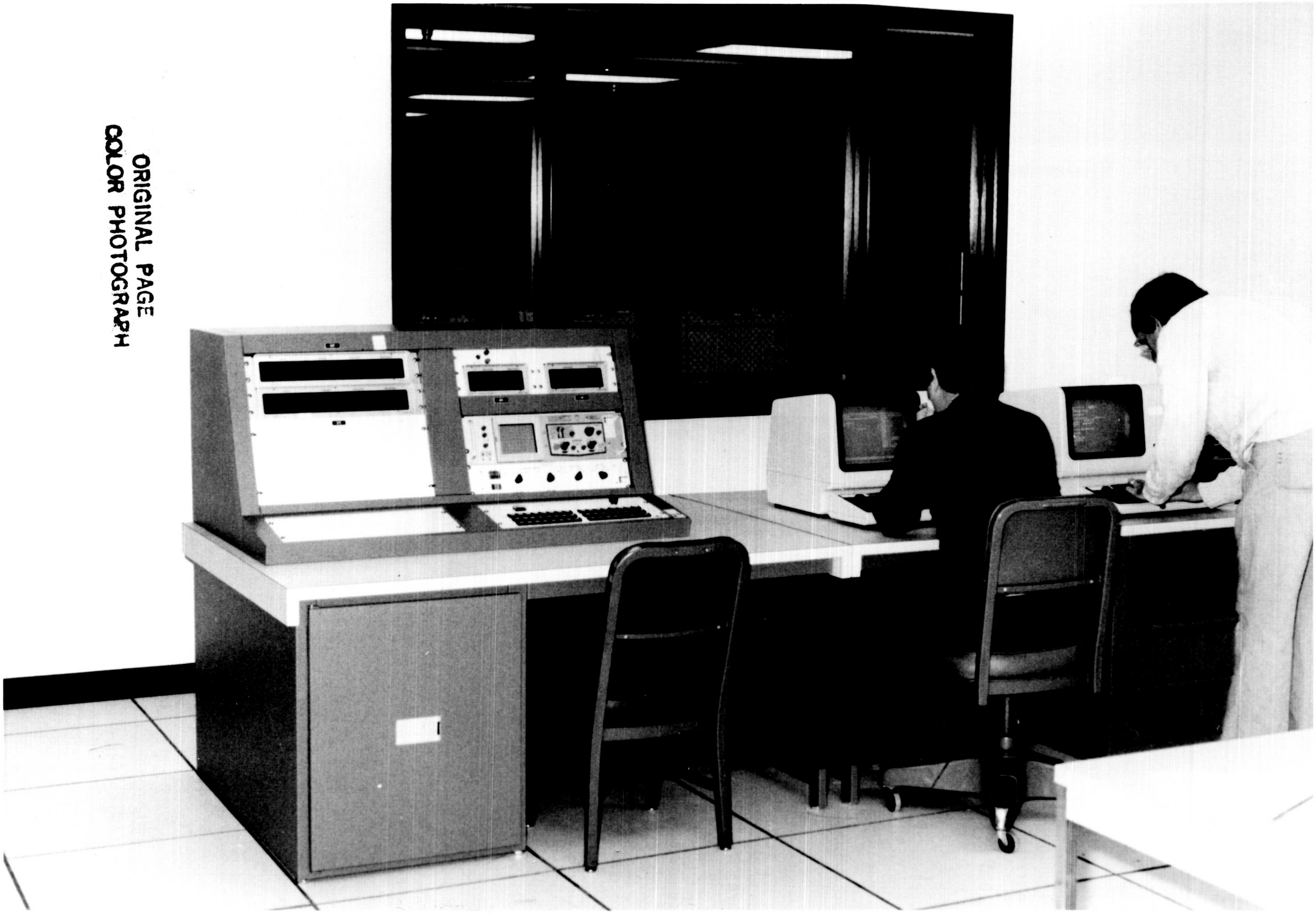

PHOTO VI. CSF SHOWING SPACECRAFT COMMAND CONSOLE

6.2.1.3 Matrix Switch

The interface between the CSF and the outside world is through Nascom lines. These lines are connected and routed within the CSF by means of the signal conditioning and switching unit (SC&SU). When the number of Nascom lines increased from three to eight, the SC&SU had to be modified. The redesign of the unit included the use of a matrix switch. The requirements for the matrix switch were that there would be no single point of failure for Flight Segment support. This requirement mandated a certain amount of redundancy for the switch. In order to keep the cost of the switch down, a design was chosen that gave functional redundancy. Engineers in Valley Forge designed and built the switch.

The switch could be configured automatically through software or manually with switches in the Mission Operations Room. As the operations became better defined in the period prior to the Landsat 4 launch, it was apparent that the design of the switch caused two problems: 1) Because of the limited number of routing options there was a lack of flexibility of configurations. This often caused delays in software development and offline processing due to the high priority of real-time operations. 2) The complexity of the switch, along with configurations of the A-channels, often resulted in the selection of wrong data paths with resultant delays or data losses.

To alleviate these problems, another switch was installed by Nascom in front of the matrix switch. This new switch allowed switching of any input and/or output line into any of the inputs to the old matrix switch. This configuration was used to support the testing, launch and operation of Landsat 4, including the interfaces with TDRSS, which could require up to four lines at the same time. The addition of the new switch added another step to the routing of the data within the control center so that the possibility of operator error in configuration increased. Because of this and the anticipation of increased switching operations to support the two spacecraft system, the NOAA contractors added a new switch for the launch and operation of Landsat 5. This new switch replaced the Nascom switch and the matrix switch. The new configuration has been used to support flight operations since January 1984.

6.2.1.4 C&DH Simulator

The original design of the Landsat control center called for a spacecraft simulator that would be used for testing and training. The design chosen consisted of a hybrid simulator that was part flight hardware and part software resident in the CSF computers. The flight hardware included in the simulator consisted of a modified version of a multi-mission spacecraft and data handling module, including the onboard computer (OBC). This design was chosen so that operations personnel could accurately test changes to the flight software for accuracy and timing. Figure 6.2-7 shows the configuration of the hardware portions of the simulator. The design of the simulator remained virtually the same throughout the program. The unit was subcontracted to Fairchild to design and assemble.

The system worked to specification when completed. However, the uniqueness of the equipment maintenance problems contributed greatly to simulator downtime. The simulator was supposed to model the Flight Segment as closely as possible and, due to evolution of the Flight Segment hardware and software, the simulator itself was constantly being updated. This, coupled with an evolving ground support system that was required for testing, caused the simulator to be behind schedule in many of the training and CSF verification activities. The complexity of the spacecraft itself often required the support of flight engineers to properly model parameters in the simulator. This requirement, however, was secondary in priority to the time-critical activities associated with preparing the spacecraft for launch.

The full-up use of the simulator required two CSF VAX computers. One computer was used to host the simulation software, while the other was used to function as the interfacing flight operations computer. This resource consumption prevented active use of the simulator after the launch of Landsat 4. It was not until the call-up of Landsat 5 for launch that the simulator system was used again.

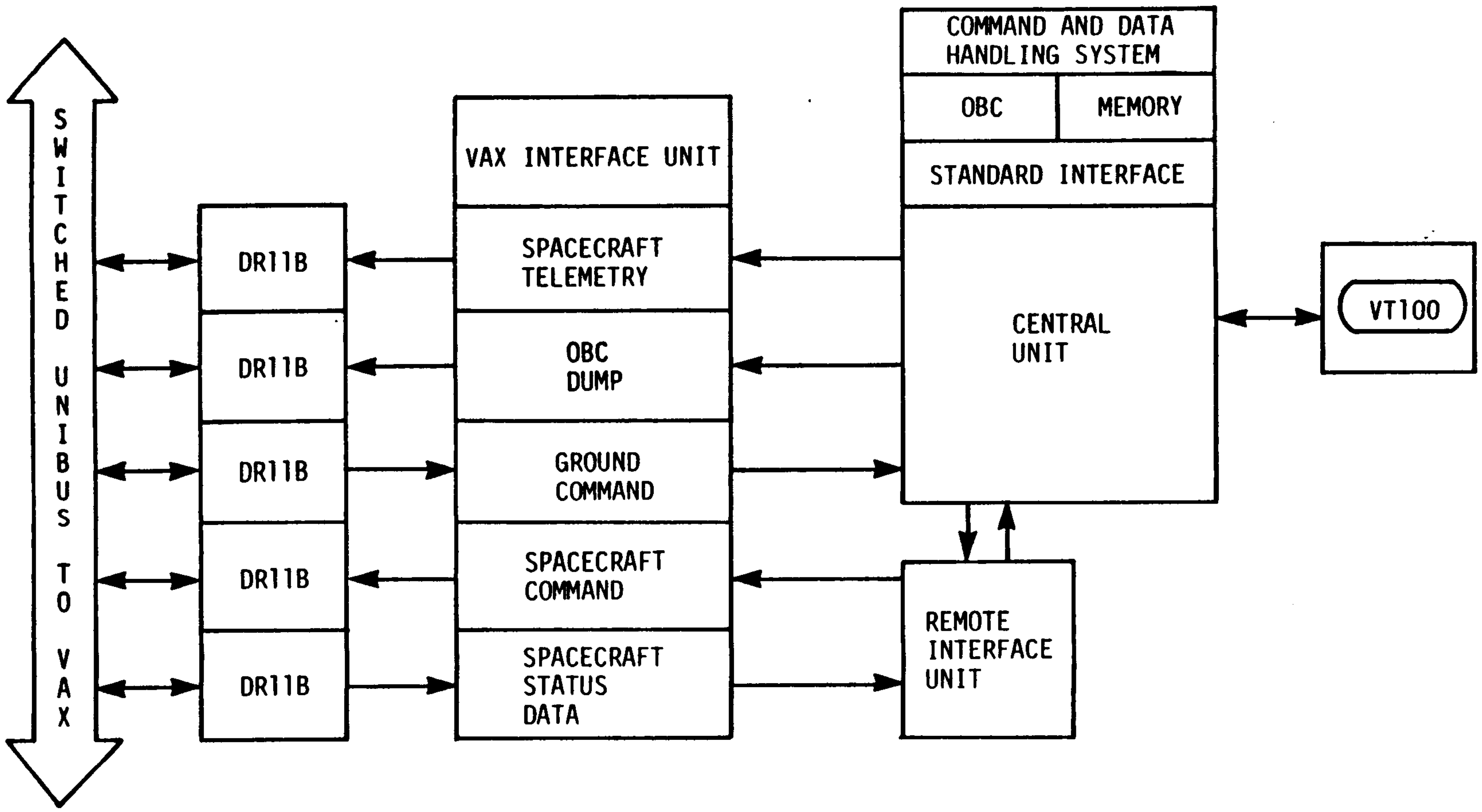

Figure 6.2-7. C&DH Simulator Configuration

6.2.1.5 Support Hardware

Contributing to the hardware configuration of the CSF were other pieces of equipment besides the major components described previously. The significant units were the drum plotter, the Mission Planning Terminal (MPT) and the Quick Look Monitor.

The drum plotter, or Houston plotter, was a mechanical plotting device utilizing three colored pens to plot telemetry data for both long- and short-term trends. This unit was connected to the CSF computers through the SC&SU and could be switched to any one of the three VAXes. The plotter itself contained a microprocessor that utilized plot instructions from the main CSF computers. Because of the resource crunch associated with the launch of Landsat 4, the plotter was connected to a MIPS computer so that engineering analysis could be accomplished without impacting real-time operations. The drum plotter provided precise and accurate information. However, it had two major drawbacks: 1) It was slow. The time required for a complete set of orbital plots could exceed 45 minutes once the plotter started. 2) It was noisy. The mechanical plotter impacted communications within the CSF because of its sustained high level of noise. It was often turned off during key operations activities. The plotter was finally moved to another area.

The Mission Planning Terminal (MPT) is the system used to support the Network Control Center scheduling interface. When it became apparent there was a requirement to support TDRSS service scheduling, a trade was made between building a system within the CSF computers and utilizing a GFE system, the MPT. It was decided to utilize the MPT for the following reasons: 1) The interface was undefined, so that the effort to support that interface could not be defined. 2) Code 500 of GSFC was developing a system that would support the interface. 3) It would be cost-effective to utilize the GFE system due to the scheduled delivery date for the MPT and its software in effect at the time the decision was made. The Landsat Project Office procured two MPT systems so that scheduling redundancy could be achieved. The MPT systems consist of a color terminal, a CPU, a disk drive and a printer. One Nascom full duplex line was utilized for the MPTs, with a switch that could control the transmit side of the terminal. The terminals were programmed by Landsat personnel with the proper identification and configuration codes. These terminals successfully supported the first Landsat/TDRSS tests in 1983.

The Quick Look Monitor (QLM) in the CSF was used by CSF operations personnel to get an early indication of instrument data and of the health of the instrument. The CSF part of the QLM consisted of an oscilloscope and a printer along with processing and routing hardware. The Data Receive, Record and Transmit System (DRRTS) could route selected MSS and TM data (one channel at a time) to the QLM in the CSF. This equipment provided valuable information to the subsystem engineers during activation and other critical data acquisition periods.

6.2.2 SOFTWARE DEVELOPMENT

The CSF software consists of five major elements plus system support software. The major elements of CSF software are shown in Figure 6.2-8. As in hardware development, the software development in the CSF was evolutionary over the course of the program, with major impacts including the selection of a Data Base Management System (DBMS) and the addition of Network Control Center interfacing software. The software development was also impacted by design growth changes as the complexity of the system was better understood. The development followed the guidelines as defined in the Software Management Plan.

Even though there was a constant evolution of requirements, the sizing of the software and the development estimates were consistent with the end results for the overall CSF. Table 6.2-3 shows the estimates that were developed for the CSF design review of September 1980 as compared with the actual results from September 1983.

After the launch of Landsat 5, modifications to CSF software became necessary. These modifications were mainly in the areas of software

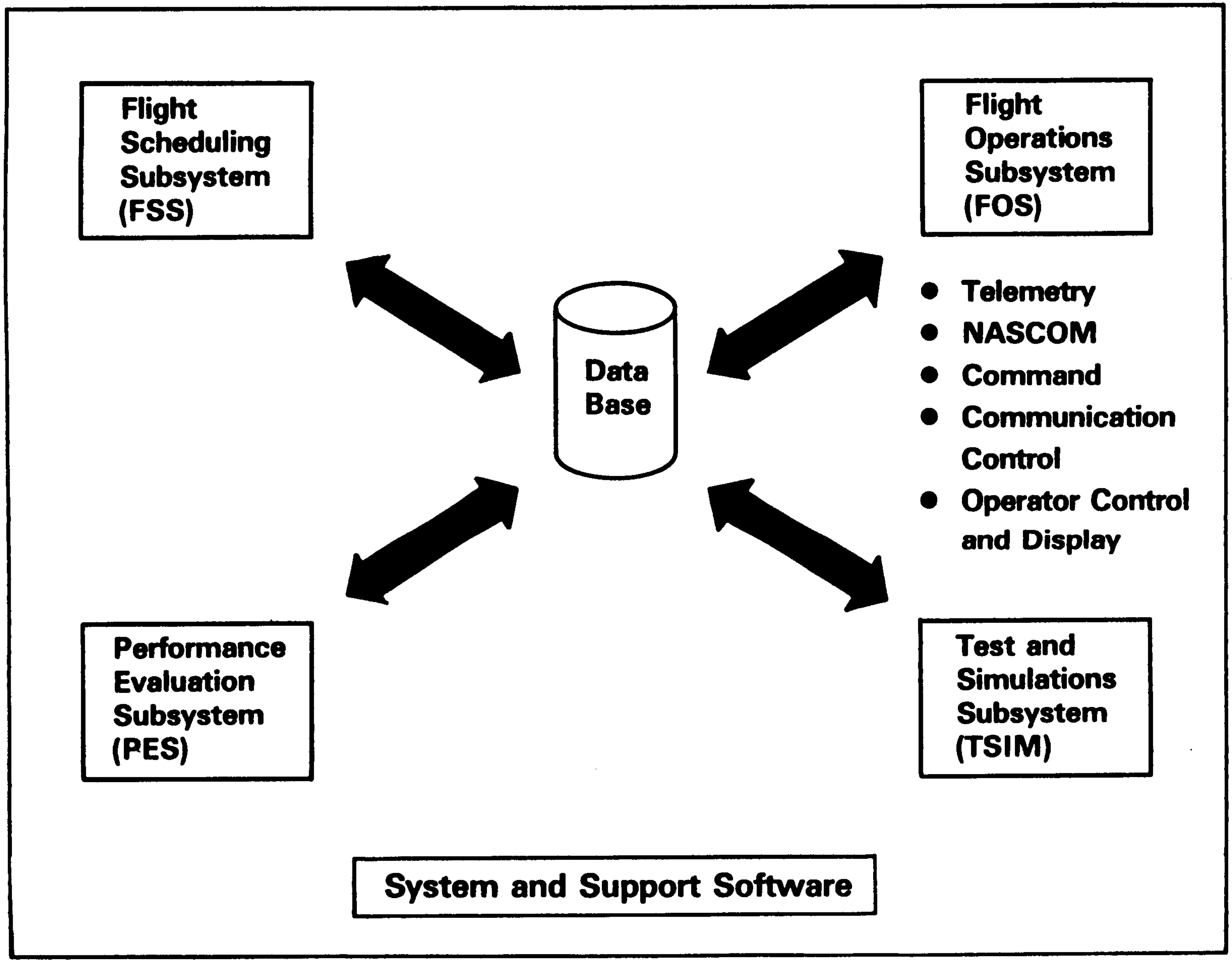

Figure 6.2-8. CSF Software Components

Table 6.2-3. Estimated vs Actual CSF Software

	LANHAM CENTER MODEL ESTIMATES (SEPTEMBER 1980)			ACTUALS (AS OF SEPTEMBER 1983)				
	LINES OF CODE (LOC)	PRODUCTIVITY* (AVERAGE)	HOURS	LOC	% DEVIATION	HOURS	% DEVIATION	PRODUCTIVITY (AVERAGE)
FOS	58,010	9.1	50,882	54,669	+6%	51,174	-1%	8.5
NCC	11,500	11.1	8,269	15,722	-27%	9,585	-13%	13.1
TSIM	29,070	13.9	16,783	29,024	0%	16,927	0%	13.7
PES	10,520	13.4	6,275	11,286	-1%	4,920	+27%	18.4
FSS	48,430	12.6	30,815	42,418	+14%	31,823	-3%	10.7
Drivers	3,300	4.0	6,600	3,497	-6%	1,487	+344%	18.8
Configuration Control			2,744			2,664	+3%	
Data Base	9,000	6.1	11,784	14,270	-37%	9,261	+27%	12.3
TOTALS	169,830	10.3	131,408	170,886	-1%	127,841	+3%	10.7

* -- LINES OF CODE PER 8 HR. DAY

efficiency improvements that allowed the CSF VAX computer loading to be increased. Since many of the functions in the CSF are data base driven, the system could support both spacecraft by having the software access the operator defined data base through initialization procedures.

6.2.2.1 Flight Operations

The Flight Operations Subsystem (FOS) is made up of the components listed in Figure 6.2-9. The primary purpose of this software is to handle the real-time command, control and communications operations of the CSF. To handle the operator interactions of these functions, a special purpose language was developed for Landsat. This language is a part of FOS and is called CSF Operator Interface Language (COIL). COIL is based on the GSFC developed Systems Test and Operations Language (STOL). The major differences are additions to handle Landsat-unique situations. COIL is a high-order language that gives the operator the capability to utilize directives and procedures to configure hardware and software and perform all of the required support operations necessary for data acquisition. The FOS software was used successfully to support both Landsat 4 and 5 launches, along with all the tests and training that were required in system integration. FOS processes consumed a large amount of CPU resources, thereby limiting terminal operations on any single VAX. Performance enhancements made between the launch of Landsat 4 and the launch of Landsat 5 gave the CPUs the capability needed to perform all functions on one computer.

6.2.2.2 Performance Evaluation

The Performance Evaluation Subsystem (PES) is a collection of software that performs analyses on the telemetry data from the Landsat Flight Segment. Figure 6.2-10 is a structure diagram of the PES software. Many of the PES reports were based on the analysis tools used in the Landsat 1-3 control center that became proven standards for determining spacecraft health. The development of operational software was contingent on completion of the FOS system and the inclusion of all required data base parameters in the resident data base. Since many of these functions were not ready until the period just before Landsat 4 launch, the PES development was not complete until after the

TELEMETRY

- REAL TIME TABLE GENERATION
- STATUS DETERMINATION
- LIMIT CHECK
- ALARM GENERATION
- OBC REPORTS
- SPECIAL TELEMETRY EXTRACTION
- GPS PROCESSING
- TELEMETRY WRAPUP

COMMAND

- SCHEDULE COMPILER
- COMMAND EDITOR
- COMMAND MANAGEMENT
- OBC DUMP COMPARISON
- COMMAND VERIFICATION
- PERIODIC PROCESSING
- MEMORY MANAGEMENT

NASCOM

- INITIALIZATION
- INPUT/OUTPUT PROCESSOR
- CATALOG BUILDER

COMMUNICATION CONTROL

- DATA MANAGER
- RAW DATA TAPE HANDLER
- OBC DUMP DATA HANDLER
- EXTERNAL TIME INTER-FACE
- FILE TRANSFER PROCESS
- SWITCHING UNIT HANDLER
- PCD HANDLER
- STR HANDLER
- COMMAND ECHO HANDLER

OPERATOR CONTROL AND DISPLAY

- DEVICE PROCESSORS
- TERMINAL PROCESSOR
- PRINTER PLOTTER PROCESSOR
- STRIP CHART PROCESSOR
- LINE PRINTER PROCESSOR
- DRUM PEN PROCESSOR
- ERROR MONITOR/LOGGER
- APPLICATION PROGRAMS
- GENERAL DISPLAY PROGRAM
- GENERAL LIST PROGRAM
- OTHER APPLICATION PROGRAM
- DISPLAY FORMAT SPECIFIER
- MNEMONIC DEFINER

EXECUTIVE

- DEVICE EXERCISES

Figure 6.2-9. Flight Operations Software

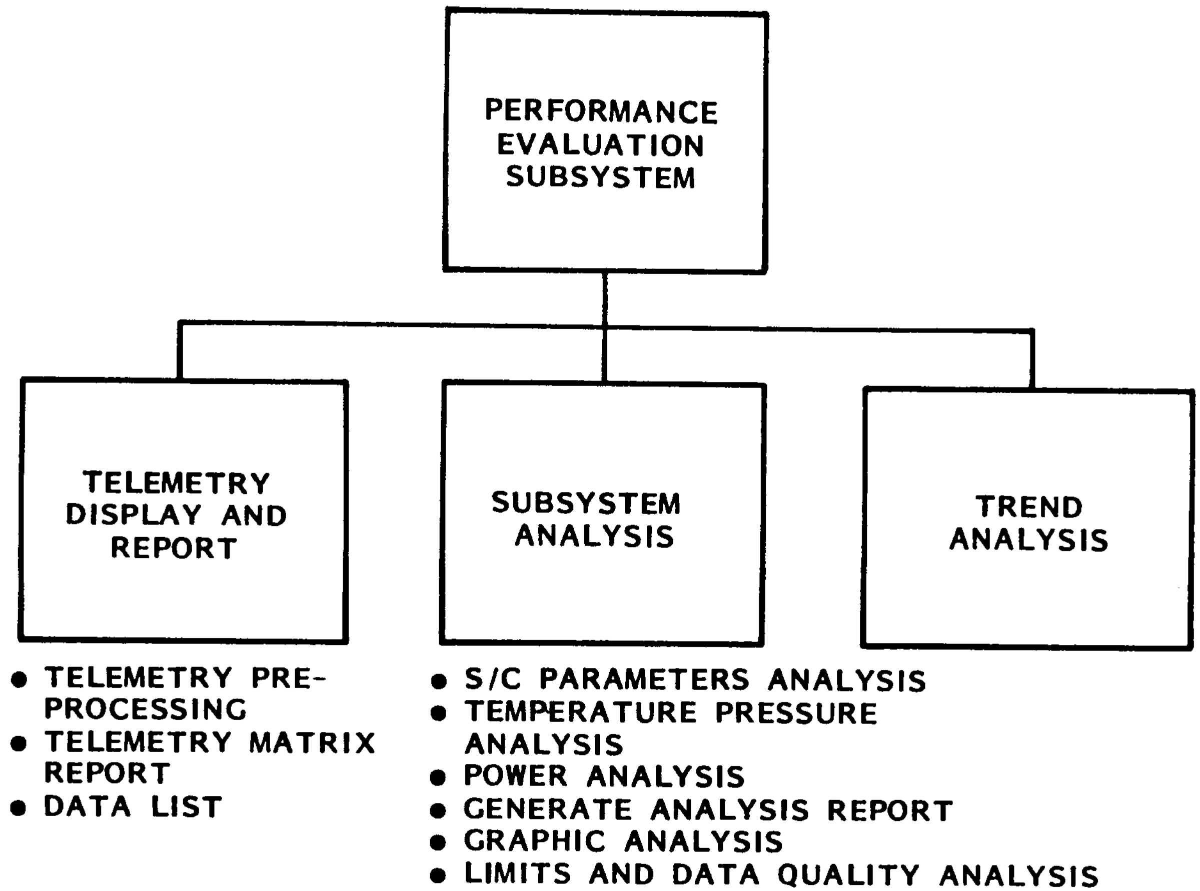

Figure 6.2-10. Performance Evaluation Subsystem Structure

launch of the spacecraft. Because of this, changes and improvements required in the PES system competed for resources with all the other launch support functions.

The PES is designed to be a user-defined tool for short- and long-term capability that can be initiated manually or through a COIL procedure. Many COIL procedures were developed for PES to support subsystem activation along with anomaly analysis.

A form of plotting using the Versatec printer was developed by the engineers at Valley Forge and installed in the CSF between the launch of Landsat 4 and Landsat 5. This tool provides rapid turnaround for investigation of parameters contained in narrowband tape recorder dumps. The Houston plotter provides better resolution in a multi-color format. However, due to the design of the software for the plotter and the slow speed of the plotter itself, rapid turnaround was not a strong point of Houston plots.

The PES software provides most of the data utilized for offline analysis along with most of the information contained in activation and performance reports. The system has proven to be extremely valuable in the support of spacecraft emergencies and recovery investigations.

6.2.2.3 Test and Simulation

The Test and Simulation (TSIM) software consists of two parts: real-time simulation and simulation support. Figure 6.2-11 shows the contents of these two TSIM modules. As mentioned previously, TSIM development was dependent upon Flight Segment development and information from Flight Segment Engineers. Because of this need, TSIM software development to the operational level was behind schedule. It took the combined efforts of Ground and Flight Segment engineers to resolve problems so that the system could be used for launch simulations.

Scenario checkpoints were a part of the TSIM software and the simulator could be brought up in either a launch or on-orbit mode. The capability to develop

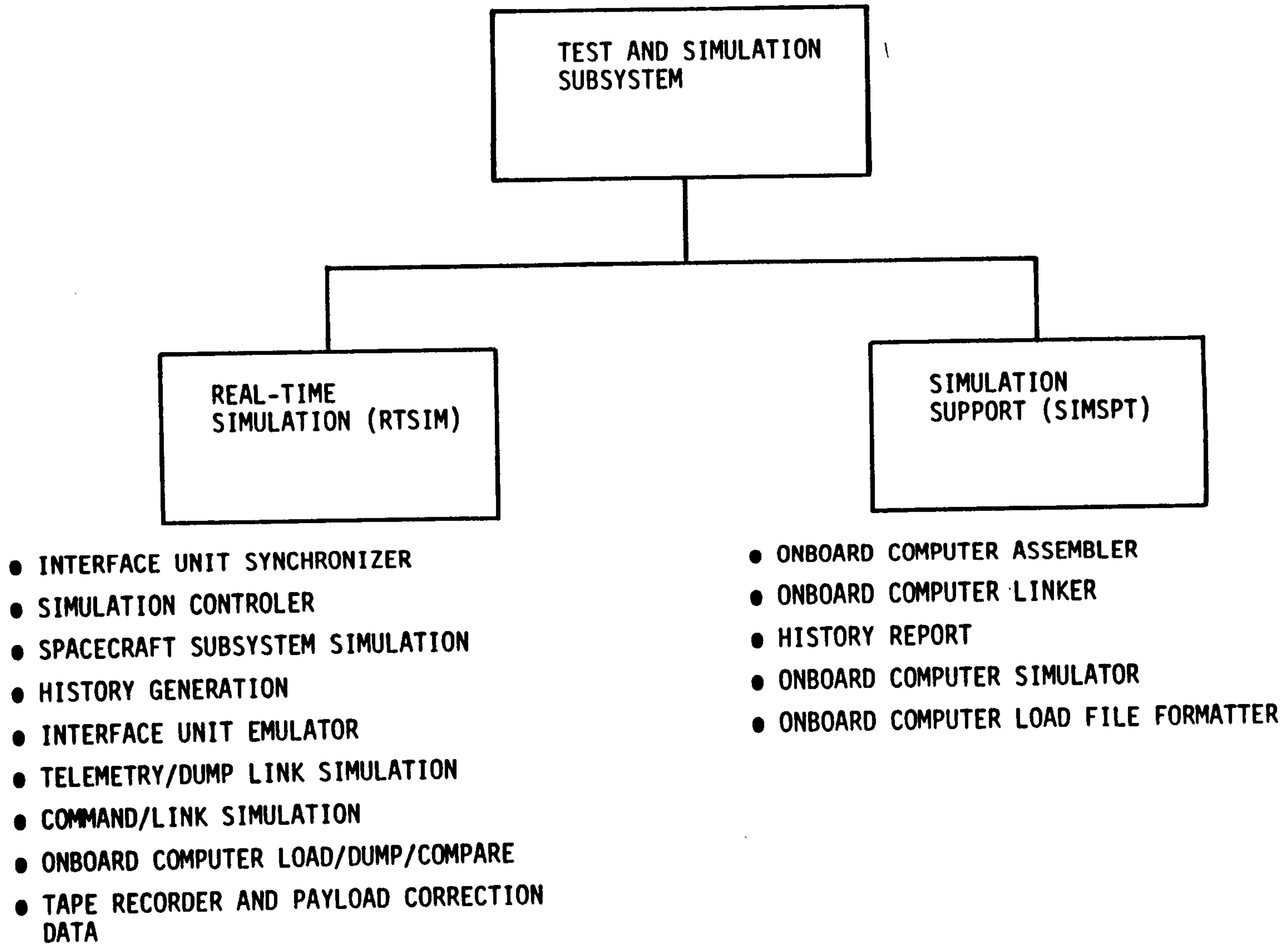

Figure 6.2-11. Test and Simulations Subsystem (TSIM)

multiple scenarios for fault training was implemented but never utilized because of the heavy emphasis on launch configurations and the previously mentioned schedule problems.

6.2.2.4 Mission Scheduling

Mission scheduling in the CSF was performed by the Flight Scheduling Subsystem (FSS) software. The FSS performs the steps necessary to provide a conflict-free schedule of Flight Segment activities. These steps include the preparation for the scheduling operation, the actual scheduling operation and post-pass acquisition analysis of Flight Segment events. Figure 6.2-12 shows the contents of the three major software groups that perform these steps. The baseline of the FSS has changed considerably since the original design. The first major set of changes were attributable to:

a. FSS/FMS Reconfiguration - the original allocation of functions between the CSF/FSS and the MMF was re-evaluated and changes were implemented in the FSS design.

b. NCC/TDRSS/GSTDN - the Network support area for data acquisition services was undefined. The original concept of all TDRSS services was changed because of delays in the TDRS system.

c. Onboard Tape Recorders - due to the delays in the TDRSS, onboard recorders were added to record the 8 Kbs telemetry data. The acquisition of tape recorder data added complexity to the FSS in that a narrowband tape recorder management scheme had to be added.

d. TM Jitter - due to the TM jitter, a compensating process was added. This process consisted of a new 32 Kbs data stream that contained Payload Correction Data (PCD). This data was used in the image processing system to compensate for the jitter caused by the mirror movement. PCD transmission was required whenever TM was activated for imaging. Additionally, whenever PCD was being transmitted, it precluded the transmission of OBC dump data or tape recorder dump data.

e. ICDs - the ICDs between Landsat and the Network/OCG were still in the negotiation phase so needed parameters for FSS could not be obtained until after the ICDs were complete.

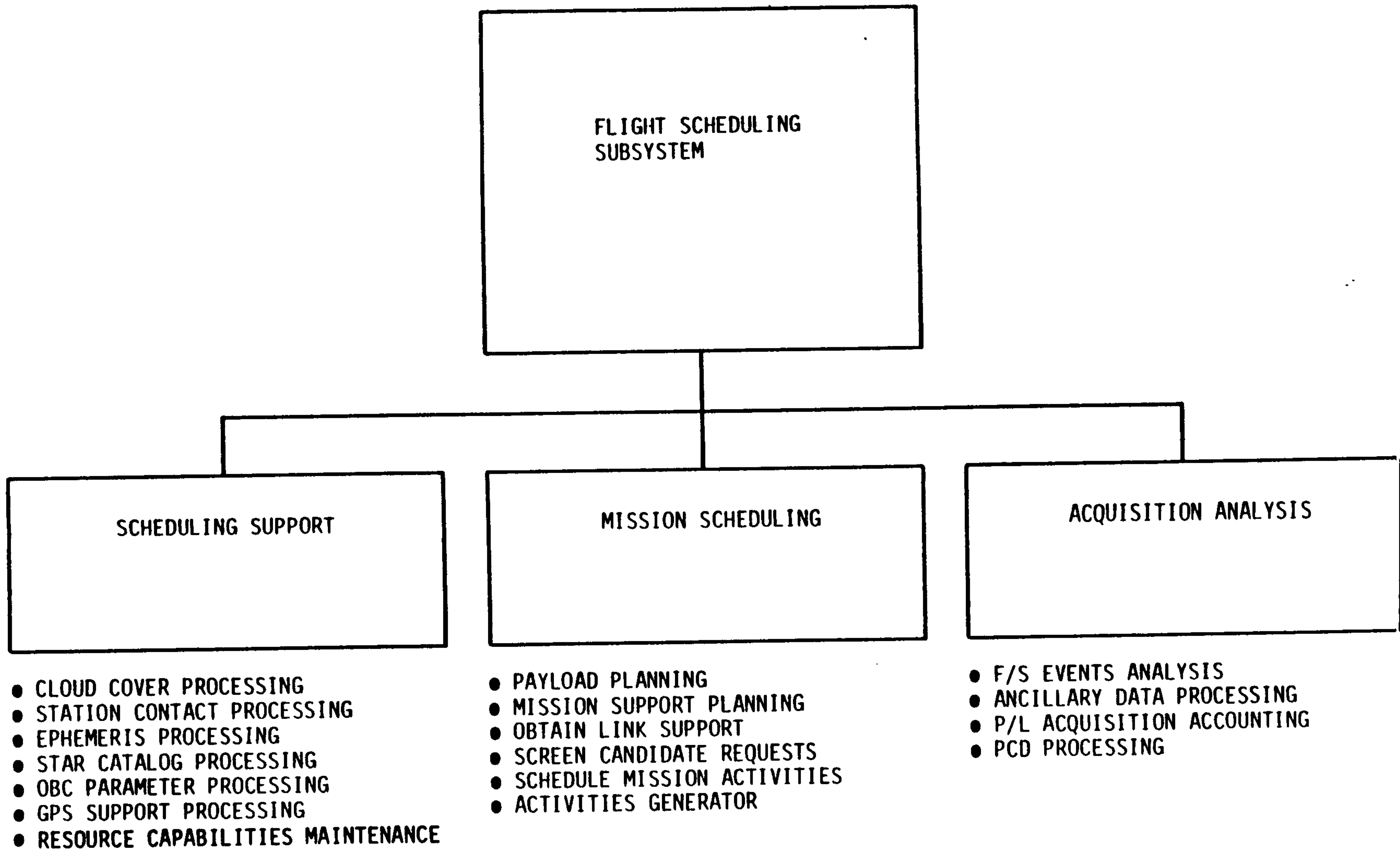

Figure 6.2-12. Flight Schedule Subsystem Software

The development of the FSS continued to lag behind schedule until the approach of the Landsat 4 launch. During this period, the importance of the FSS to operations mandated that recovery tiger teams be formed. These teams worked around the clock until the FSS was in condition to support operational activities after launch.

One of the driving factors that dictated the basic philosophy for the scheduling system was whether data acquisition would be through ground station (GSTDN) or through TDRSS. The original design called for a system based on a full-up (2) TDRS system. Slips in the TDRSS schedule resulted in requirements for a GSTDN only design. This caused a major redesign of the FSS. The differences in the nature of support for the full TDRS FSS designs precluded a mixed FSS system. The result was two separate scheduling systems in the CSF, one for GSTDN only and one for full-up TDRSS. After NASA launched the first TDRS, there was a need for a limited TDRSS FSS. This need, along with the limited power available on Landsat 4 due to a solar array problem, resulted in the development of the interim scheduling system for one satellite TDRS support. This interim system was never in full operational use for the following reasons. The problems that occurred in the launch of TDRS-A caused a deferral of the second TDRS launch. Coupled with this, the network was undergoing extensive acceptance testing of the TDRS system. As a result, the CSF has been utilizing the GSTDN FSS for the majority of both Landsat 4 and Landsat 5 scheduling needs, and manually modifying the schedule whenever a TDRS support was added.

6.2.2.5 Network Interface

The original baseline design of the CSF did not call for a special subsystem to deal with the Network interface. However, once the impact of the NCC/TDRS system was understood, the requirement arose for a software system to handle the newly-identified interface. The Network Control Center Subsystem (NCCS) is the software subsystem designated to handle the message traffic between the NCC and the CSF. This subsystem's structure is shown in Figure 6.2-13. The format and content of the messages to be handled were agreed to in an ICD with

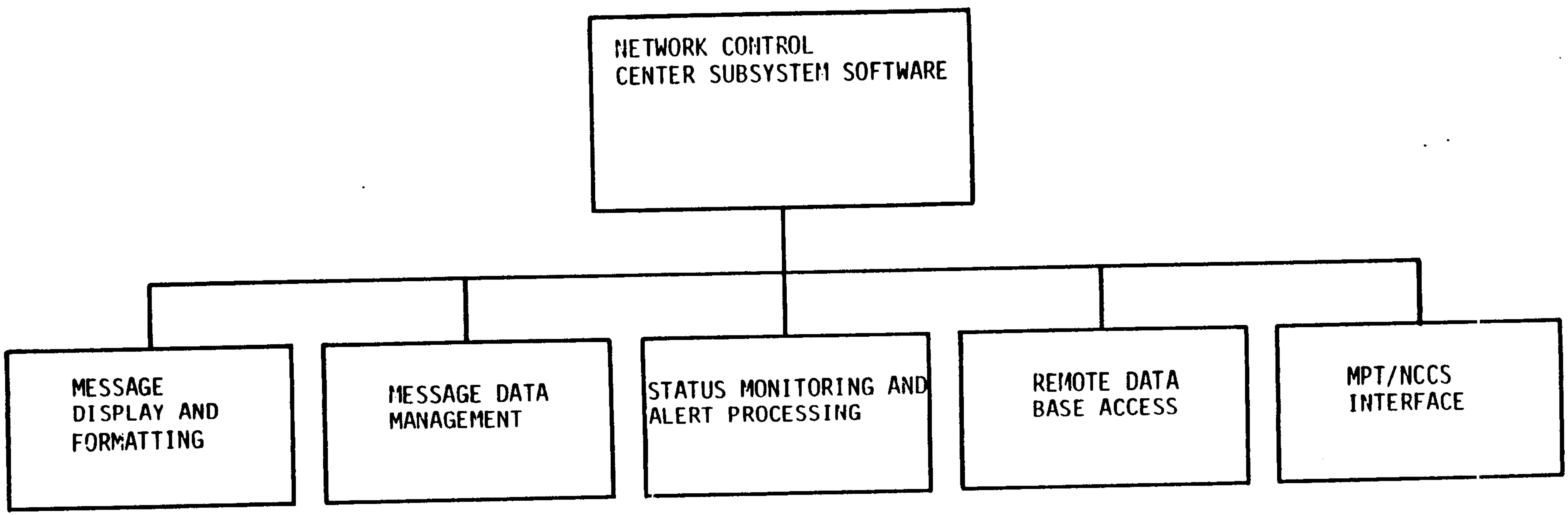

Figure 6.2-13. Network Control Center Subsystem Structure

the NCC. Also, a part of the NCCS is the operator interface between CSF scheduling and the MPT. This interface is required because all of the TDRS scheduling requests and actual schedules are transmitted and received through the MPT. This information is entered in the FSS process so that the schedules can be produced without conflict.

The majority of NCCS operations are real-time support functions. These support messages are data base defined for format and operator defined for variable content. The NCCS was used extensively for NCC interface testing and successfully supports the actual TDRSS acquisitions.

6.2.2.6 Data Base

The CSF data base is not a separate subsystem within the CSF software. It is software that supports the other subsystems by storage and manipulation of parameters. The CSF data base is significant in that the original design of the CSF did not have a DBMS. During early 1980, when the impact of the NCCS proposal was being studied, various alternatives were being examined to provide data file storage and access. Since the VAX computers selected for the CSF were a relatively new system there was little historical data upon which to base a decision. The Digital Equipment Corporation (DEC) had not yet developed a VAX based DBMS so an outside vendor was sought. After a performance study was completed, a DBMS called SEED, developed by International Data Base Systems, was selected. Although the cost of implementing SEED in the CSF was expensive due to the vendor price, DBMS was installed because of the pressing need for a data base manager and the anticipated performance improvements. Along with SEED, support software was acquired from the vendor for a query language (HARVEST), an on-line interactive data manipulation language (GARDEN) and a transaction processor (SPROUT). The SEED data base was used in FSS, FOS and NCCS and provided a structured storage and retrieval system for the CSF.

Although SEED provided a powerful tool for CSF software development, problems were encountered. The first problem was that SEED was complicated to use. The data base administrator (DBA) was required to build and load the system.

This position required extensive training and personnel turnover resulted in the DBA being behind the curve in the development area. The second major problem area was the lack of documentation in the structure of the data base. This information could have helped the subsystem engineers in the input definitions for the data base. The third major problem area was the access speed of data base interactions. This problem severely hurt the run duration of the Flight Scheduling System because of the FSS need to store and access thousands of bits of data for each scheduling run.

6.3 DATA RECEIVE, RECORD, TRANSMIT SYSTEM (DRRTS)

The Data Receive, Record, Transmit System (DRRTS) functions were specified as part of the Data Management System (DMS) in the NASA specification. The major functions allocated to DRRTS were:

a. Receive and record Landsat 4 multispectral scanner (MSS) and thematic mapper (TM) data on high density tape (HDT). The sources of the data for MSS were:
   1. Transportable Ground Station in real-time at 15.06 Mbps
   2. Tracking and Data Relay Satellite System (TDRSS) in a bent pipe mode; i.e., real-time through the TDRSS satellite to White Sands and retransmitted to GSFC via Domsat.
   3. 14-track HDTs from foreign sites.

   The sources of the data for TM were:
   1. Transportable Ground Station in real time at 84.9 Mbps
   2. Via TDRSS at 1/2 real-time rates. The White Sands TDRS receive site records TM data in real-time and later retransmits it to GSFC via the Earth synchronous domestic satellite (Domsat) whose maximum bandwidth is 50 MHz.
   3. 28-track HDTs from Prince Albert, Canada
b. Transmit MSS archive data to the EROS Data Center at 15.06 mbps
c. Copy MSS and TM high density tapes, either unprocessed or processed
d. Generate tape directories for MSS and TM unprocessed tapes, which include mirror sweep correction data for TM, and send to the Mission Management Facility
e. Extract MSS/TM sensor data and send to the Control and Simulation Facility (CSF) for a Quick-Look Display
f. Store MSS/TM in a tape archive (short-term).

The hardware configuration of DRRTS as implemented is shown in Figure 6.3-1.

6.3.1 HARDWARE DEVELOPMENT

General Electric originally proposed a Digital Equipment Corporation PDP 11/03 as the controller for the DRRTS hardware. This was changed to a PDP 11/34 for increased capability in memory, speed and software development tools. The

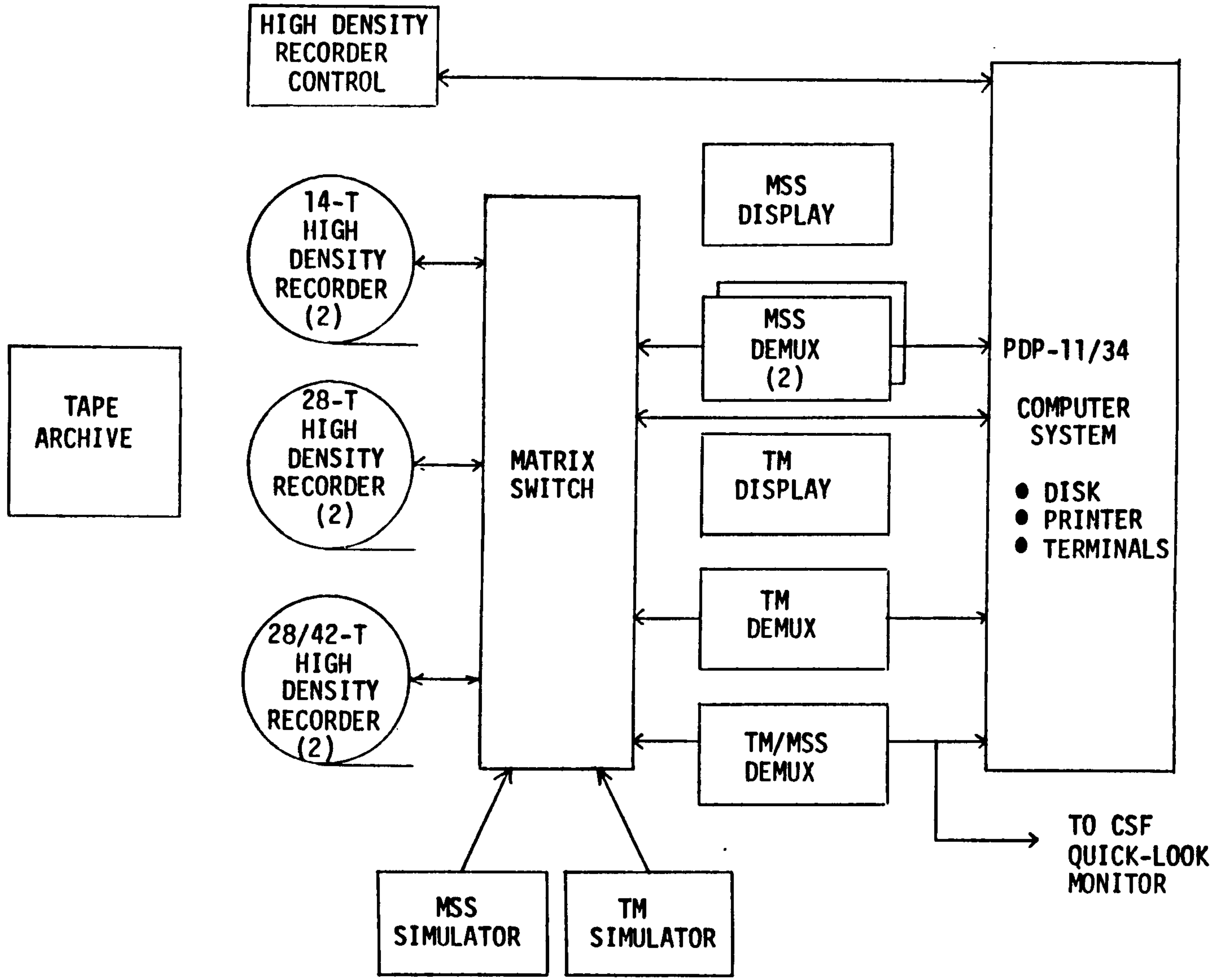

Figure 6.3-1. Data Receive, Record, Transmit System Hardware

DRRTS software architecture was driven by special purpose hardware, the system functions and a menu-driven operator display. DRRTS control software was implemented in approximately 23,000 lines of code (LOC).

DRRTS was proposed to be the central recording facility for the DMS, controlling high density recorders for image processing along with performing the functions mentioned above. The control of the image processing recorders was moved to the image processing strings (MIPS and TIPS) to simplify development and testing. The design of DRRTS was ultimately limited by the 11/34 capabilities for extracting and storing data.

General Electric originally proposed five 14-track and five 28-track high density digital recorders (HDDR) built by Bell & Howell to be the high-speed recording medium in DRRTS. This evolved to five 14-track and five 42-track recorders built by Martin-Honeywell to be compatible with existing NASA purchases and therefore reduce costs. After the record/playback function for each processing string was moved, DRRTS had the following HDDR configuration: two 14-track, two 28-track and two 28-track (expandable to 42-track) built by Martin-Honeywell. The recorder design included error correction capability and had better performance than the bit error rate specifications. The 28-track recorders were capable of recording data rates up to 85 Mbps. Pre-selected speeds were designed in the DRRTS recorders to allow them to record the various data rates required (15.06, 30.12, 45.18, 42.2 and 84.4 Mbps). These recorders are synchronized to the data rates by external programmable frequency sources. The 28-track system also included a timing subsystem to generate and read IRIG times on the tape, and a tape search unit that enabled computer or local control of the recorder system.

The DRRTS special purpose hardware consisted of two MSS demultiplexers built by MacDonald-Dettwiler, plus one TM demultiplexer, one matrix switch and one MSS/TM demultiplexer built by General Electric. As originally proposed, one type of demultiplexer was to be used for both MSS and TM. However, separating the MSS and TM processing permitted use of MSS demultiplexers that were purchased as off-the-shelf hardware, increasing the reliability of the MSS processing.

The TM demultiplexer was a state-of-the-art design to extract information necessary to generate a tape directory from the incoming TM data stream. It included sophisticated logic to account for bit slips and sync losses and additionally had a separate subsampled video display that allowed early visual confirmation of data quality. A TM/MSS demultiplexer furnished extracted sensor data for a quick-look monitor used for monitoring detector performance.

The matrix switch was the electrical interface between recorders and the demultiplexers. It was designed to switch both digital data and analog timing signals from/to any recorder to any demultiplexer. It also included built-in loop back test capability to validate the operability of the receiving terminal equipment for the White Sands and EDC links.

DRRTS contained an MSS data simulator built by MacDonald-Dettwiler and a TM data simulator built by General Electric. Both devices, augmented by test tapes obtained during spacecraft testing, were used for validating both hardware and software during development and provide operational capability for fault isolation.

Photo VII is a view of the DRRTS System.

6.3.2 SOFTWARE DEVELOPMENT

The DRRTS software structure is shown in Figure 6.3-2. It includes the RSX-11/M operating system, a Fortran IV-Plus compiler, and the DECNET networking software supplied by DEC. An extension of this vendor software, the DRRTS system software, was developed in-house. The system software includes hardware device drivers for non-DEC supplied hardware and associated hardware diagnostic software.

The operator interface program controls all CRT displays and hard copy devices, the printing of HDT labels, as well as the reading of labels via an optical character reader, and allocates resources to various DRRTS functions

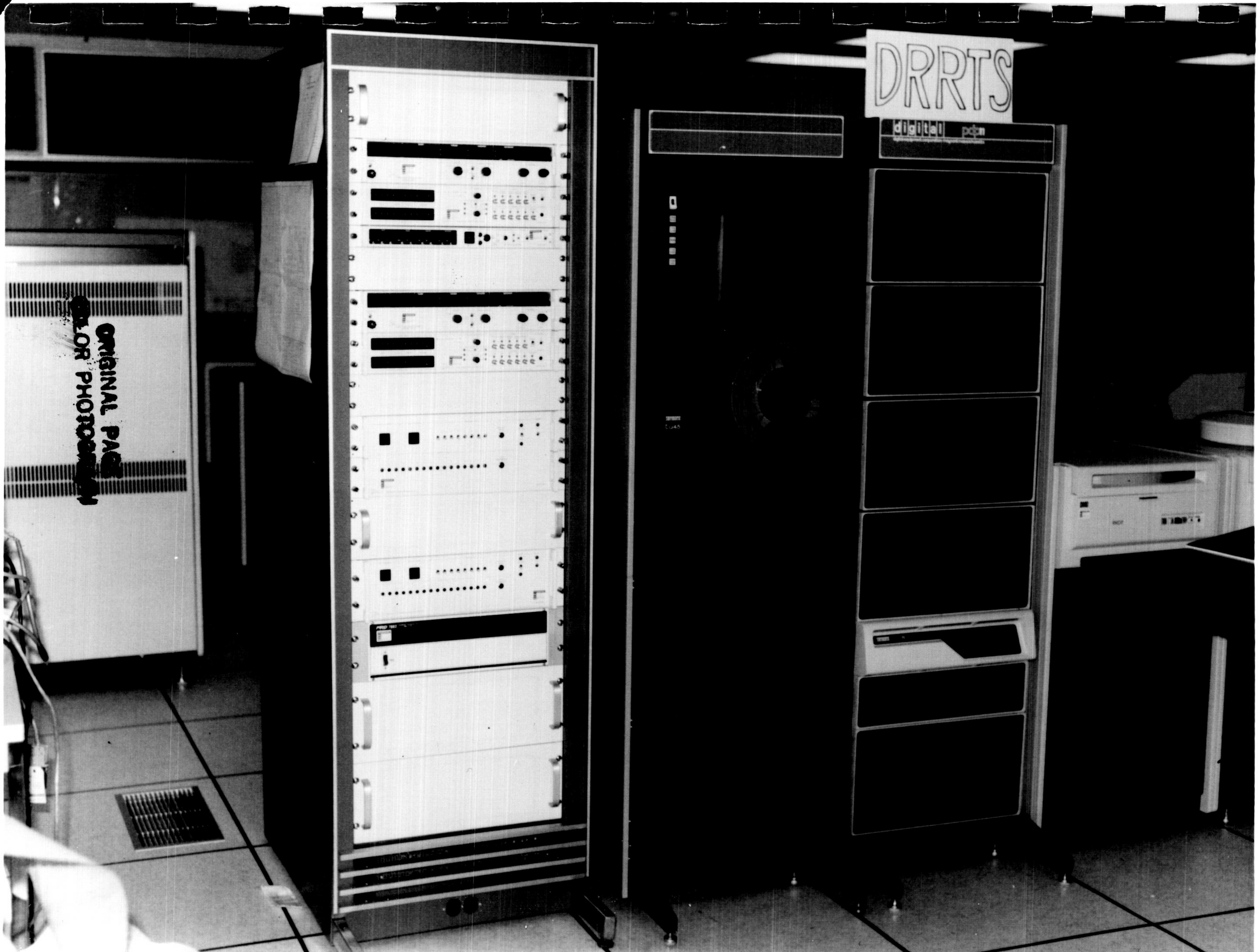

PHOTO VII. DRRTS SYSTEM

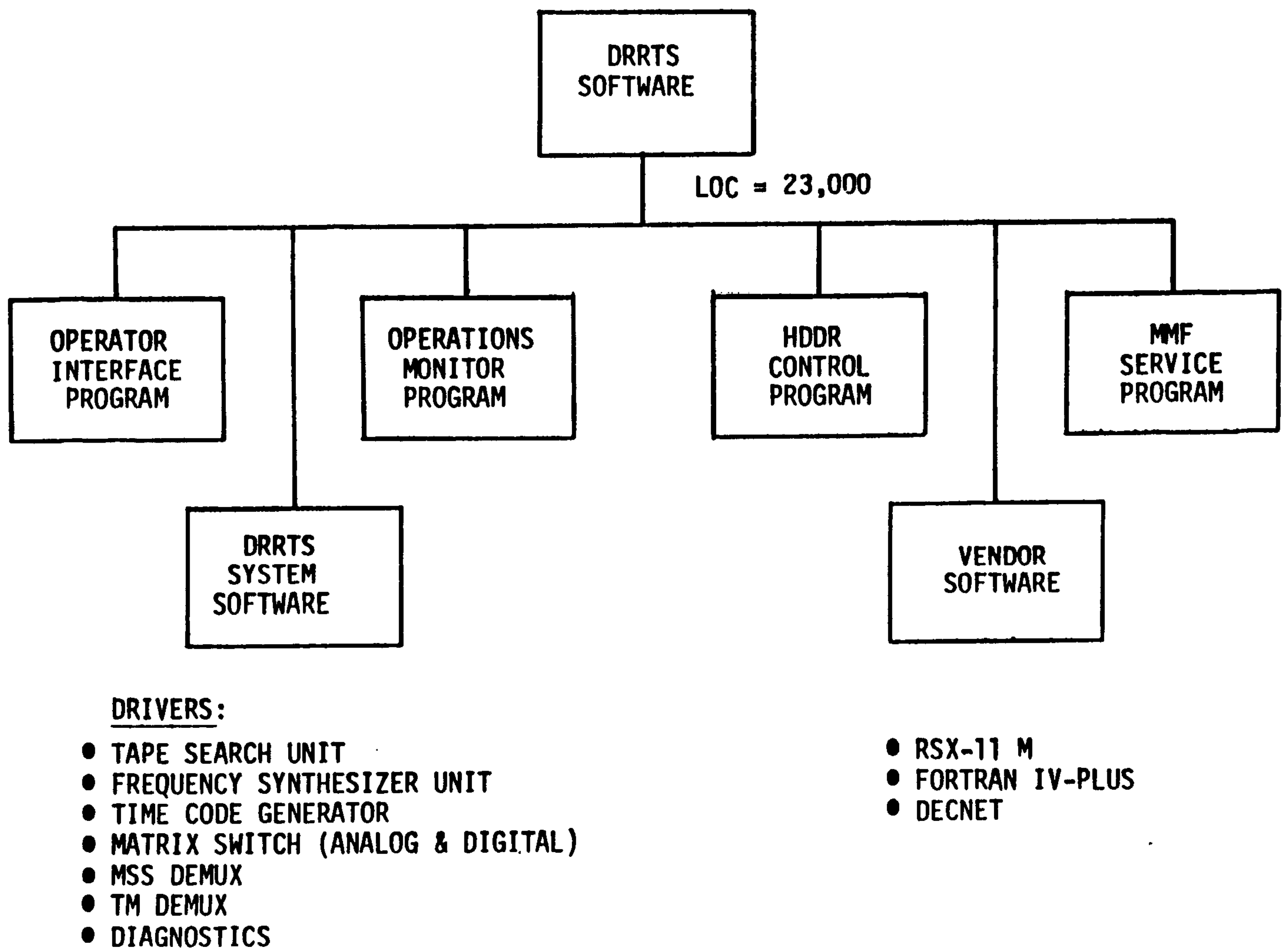

Figure 6.3-2. DRRTS Software Conceptual Design

setting data paths via the matrix switch. In addition, the program directs line tests of the various communications links to and from the DRRTS.

The operations monitor program controls the progress of multiple operations, displays status and error messages for the operator via the operator interface program and controls the generation of HDDT directories.

The high density digital recorder (HDDR) control program directly controls the HDDRs. It processes their status and generates any resulting status and error messages. It also generates quality files for quality assessment of the tapes.

The MMF service program controls the DRRTS side of the MMF to DRRTS interface using vendor-supplied DECNET software. It handles the higher level of MMF to DRRTS file exchange protocol, generating alerts when new process requests enter DRRTS and providing appropriate request feedback to the MMF.

6.4 MSS IMAGE PROCESSING SYSTEM

The MSS Image Processing System (MIPS) performance and production requirements are shown in Tables 6.4-1 and 6.4-2, respectively. The overall processing flow is shown in Figure 6.4-1. The input to the MIPS is a 28-track high density tape recorded in the DRRTS. The data is stored on disk after reformatting. Geometric and radiometric corrections and other annotation data are computed. The image data is then radiometrically corrected, with tables included for geometric corrections, and written to a 28-track archival tape that can be evaluated before it is returned to DRRTS for transmittal to the EROS Data Center.

Three identical processing strings (Figure 6.4-2) are provided. One spare 28-track high density digital recorder is switchable to any processing string.

MSS Payload Correction

The Payload Correction Subsystem (PCS) processes telemetry data to produce geometric correction functions that correct for systematic errors in the imagery. This process is performed on the DEC 2050. It involves the smoothing, validating and propagating of both the attitude and ephemeris data followed by the generation of scene correction data (scene center, location and identification) and transformation of the data to a standard coordinate system.

MSS Archive Generation

The MSS Archive Generation (MAG) function generates partially processed data and MSS data products from unprocessed image data. The data processing steps that are performed to accomplish this include radiometric and geometric correction, ancillary data generation, manual cloud cover assessment and generation of 70 mm film for quality assurance inspection.

The process begins with the receipt of a process request (PR) from the MMF or an operator generated engineering request. The PR specifies those intervals (up to 35 contiguous scenes) of data on the 28-track high density tape that are to be processed. MAG then reads the MSS correction parameter file

Table 6.4-1. MSS Image Processing Performance Requirements

REQUIREMENT	MSS PROCESSING SYSTEM
TURNAROUND TIME	48 HOURS MAXIMUM • RAW DATA TO ARCHIVAL HIGH DENSITY TAPE • WITH ANY SINGLE POINT FAILURE
MAXIMUM UTILIZATION	85% OF 16 HOUR DAY
RADIOMETRIC ACCURACY	$\pm$1 QUANTUM LEVEL
MAP PROJECTIONS	SPACE OBLIQUE MERCATOR UNIVERSAL TRANSVERSE MERCATOR/POLAR STEREOGRAPHIC
RESAMPLING ALGORITHMS	CUBIC CONVOLUTION NEAREST NEIGHBOR
GEOMETRIC ACCURACY*	
• TEMPORAL REGISTRATION	0.3 PIXEL (90% OF THE TIME)
• GEODETIC	0.5 PIXEL (90% OF THE TIME)

*WITH SUFFICIENT CORRELATABLE GROUND CONTROL POINTS

Table 6.4-2. MSS Image Processing Production Requirements

OUTPUT	NAME	USE	VOLUME(SCENES/DAY)
HIGH DENSITY TAPE – ARCHIVAL	HDT–AM	USER PRODUCT	200
COMPUTER COMPATIBLE TAPE–ARCHIVAL	CCT–AM	PERFORMANCE EVALUATION	TOTAL OF 2
COMPUTER COMPATIBLE TAPE–PRODUCT	CCT–PM	PERFORMANCE EVALUATION	
241 MM FILM – ARCHIVAL	F241–AM	PERFORMANCE EVALUATION	TOTAL OF 4
241 MM FILM – PRODUCT	F241–PM	PERFORMANCE EVALUATION	
70 MM FILM – ARCHIVAL	F70–AM	PERFORMANCE EVALUATION	200 (IN ONE BAND)

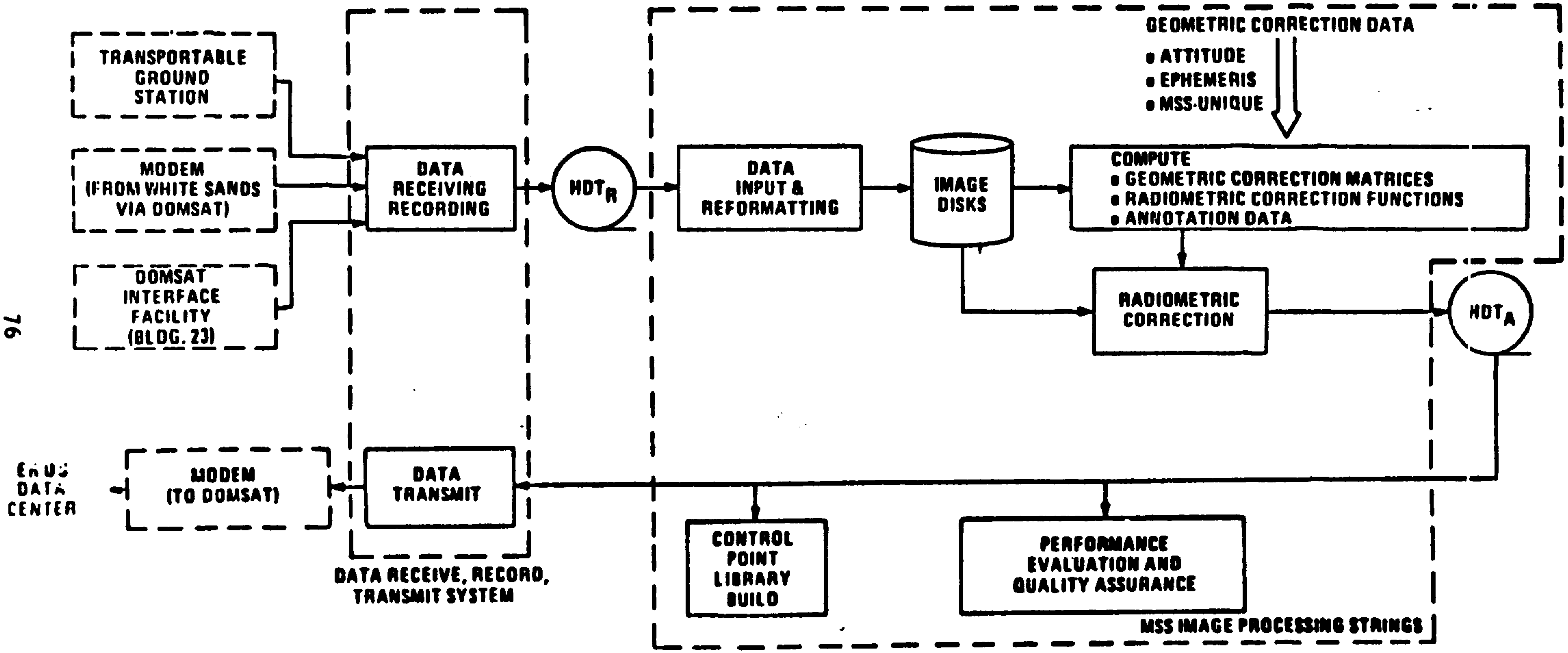

Figure 6.4-1. Multispectral Scanner Image Generation Process Flow

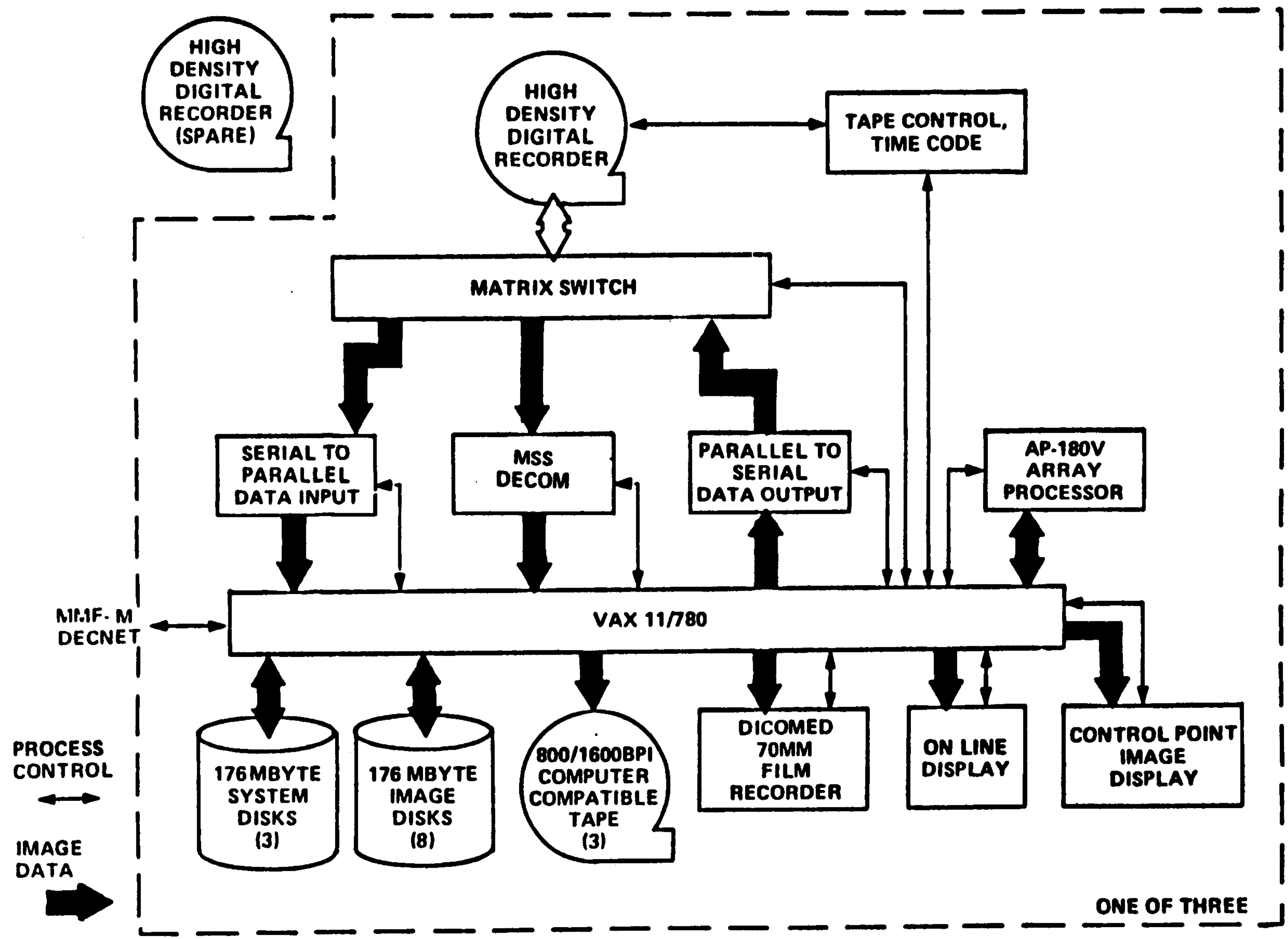

Figure 6.4-2. MSS Image Processing System Hardware

generated by the Payload Correction Function and the specified unprocessed image data from the HDT-RM.

Next, MAG extracts subsampled image data, for each interval of data read from the HDT-RM, for manual cloud cover assessment and 70 mm film generation. This subsampled data is used for reference to assess the overall quality of the image data on the HDT-RM. Next, control point neighborhoods, calibration wedge values and histograms for the geometric and radiometric correction data processing functions are obtained from the image data and the radiometric correction tables, geometric correction matrices and ancillary data for the image data are produced. Finally, MAG generates the archival high density tape (HDT-AM) and the process request feedback to the MMF. Data is read from the disk, the radiometric corrections are applied in the array processor and then it is sent through the Parallel to Serial Data Output (PSDO) device and the matrix switch to write to the HDDR.

The radiometric and geometric functions are both calculated in the AP 180 Array Processor. Data is read from disk to the array processor and written back to disk. Cloud cover assessment is an operator interactive process that displays the subsampled images to the operator and solicits response for the estimated percentage of cloud cover for each image on a quadrant basis.

MSS Performance Evaluation and Product Generation

The MSS Performance Evaluation and Product Generation (PEPG) function provides the capability to evaluate archival high density tapes or produce film and computer compatible tape (CCT) products for the evaluation of the computed correction data. These processes can be initiated via a PR from the MMF or locally by the operator.

The archival high density tape is read from the HDDR, through the matrix switch and Serial to Parallel Data Input (SPDI) to disk. Both partially corrected (CCT-AM) and fully corrected (CCT-PM) tapes can be generated along with performance evaluation reports and Comtal image displays.

High resolution film (241 mm) could also be generated by this process using the TM Image Processing System (TIPS) hardware.

MSS Control Point Library Build

The MSS Control Point Library Build process is used to create a library of both geodetic and supplemental control points in the MMF. If available for the scenes to be processed, these control points are included in the MAG PR and are automatically used in the geometric correction process. They allow the radiometrically corrected archival data to be corrected to a 0.5 pixel geodetic registration accuracy and a 0.3 pixel temporal registration accuracy. The process of building the Control Point Library includes:

a. Scene Selection - The priority of scenes from which to select control points is made by the NOAA Program Office based upon the current content of the Control Point Library and anticipated program needs. Cloud free scenes of high digital quality are selected by interactive examination of the MMF data base and examination of quality assessment 70 mm film files.

b. Selecting Candidate Geodetic Control Points - Up to 25 well-distributed candidate geodetic points (GCPs) are selected representing features observable on both 241 mm film and standard maps. The location of each GCP is marked on the map.

c. Digitizing Candidate Control Points - The latitude and longitude of all GCPs are located to within 0.37 mm using a sonic digitizer. On standard USGS 1:24,000 scale maps this corresponds to an accuracy of 0.16 pixel. The MIPS collects information on all candidate GCPs in a scene and transmits that information to the MMF.

d. Control Point Generation - The process of selecting control points is an interactive one, utilizing radiometrically corrected imagery overlayed with annotated maps to locate supplemental control points to augment the geodetic control points.

6.4.1 HARDWARE DEVELOPMENT

The MSS image processing automatic data processing equipment was substantially changed from that originally proposed. The proposed system had a Digital

Equipment Corporation (DEC) PDP 11/70 controlling a General Electric Federation of Functional Processors (FFP) that performed the image processing algorithms. There were two strings each capable of processing either MSS or TM data.

The PDP 11/70s were replaced with DEC VAX 11/780s after a trade study showed that additional speed and capability using the 32-bit architecture could be realized with little cost or schedule impact. The system still used FFPs for data decommutation and geometric correction. When the MSS processing functions were separated from the TM, the FFPs were replaced by an off-the-shelf array processor (AP-180V), the VAX compatible version of the AP-120B.

The high density digital recorders (HDDRs) used in MIPS were identical to those 28-track HDDRs used in DRRTS. The recorders are controlled directly from the VAX utilizing the tape search unit. IRIG times can be read from or written to the tapes using the timing subsystem. The speed is controlled by externally programmable frequency synthesizing. The MIPS strings have a spare HDDR that can be switched to any string.

The MSS system uses Comtal 512 x 512 pixel displays. These displays are used to verify system performance, examine image quality and assess cloud cover for archive generation and the PEPG process.

The MSS Decom built by MacDonald-Dettwiler synchronizes to the MSS data stream, extracts the time code from the data, performs line length calculations, extracts the calibration and detector data, and demultiplexes and reformats the detector data for input to the VAX 11/780. The synchronizer portion is identical to that in the DRRTS demultiplexer, the Decom adds a buffer memory. This function was originally proposed to be done by a decommutator built by General Electric that could be used for both MSS and TM. This approach was abandoned in favor of the commercially available MDA decom when the TM and MSS functions were separated.

The SPDI and PSDO perform the serial and parallel conversions and data buffering functions between the computer and the HDDR.

As proposed there was one Dicomed 70 mm film recorder shared between two strings. As implemented there is one for each string.

Figure 6.4-2 shows this layout. Photo VIII shows the hardware.

6.4.2 SOFTWARE DEVELOPMENT

The MIPS software structure shown in Figure 6.4-3 logically grouped functions and allowed for separate software development teams. The bulk of the MIPS software was written in Fortran. It consisted of approximately 157,000 lines of code.

Three different kinds of software were utilized in MIPS: applications software, developed by GE, vendor-supplied software, and system software, developed by GE to support non-standard peripheral devices.

Additionally, parameter files were designed and used to supply values of time variant and invariant constants.

6.4.2.1 APPLICATIONS SOFTWARE

6.4.2.1.1 MSS Control and Communications

The Control and Communication Package (CCP) software executes independently on each MIPS string to control basic string operations, communicate with MMF and handle individual work items. The software is arranged as an executive process with numerous supporting processes. Each supporting process provides a single, specific service to the executive process. Since most of these supporting processes are complex data processing functions, performing them separately reduces the complexity of the executive substantially.

PHOTO VIII. MIPS-2 HARDWARE

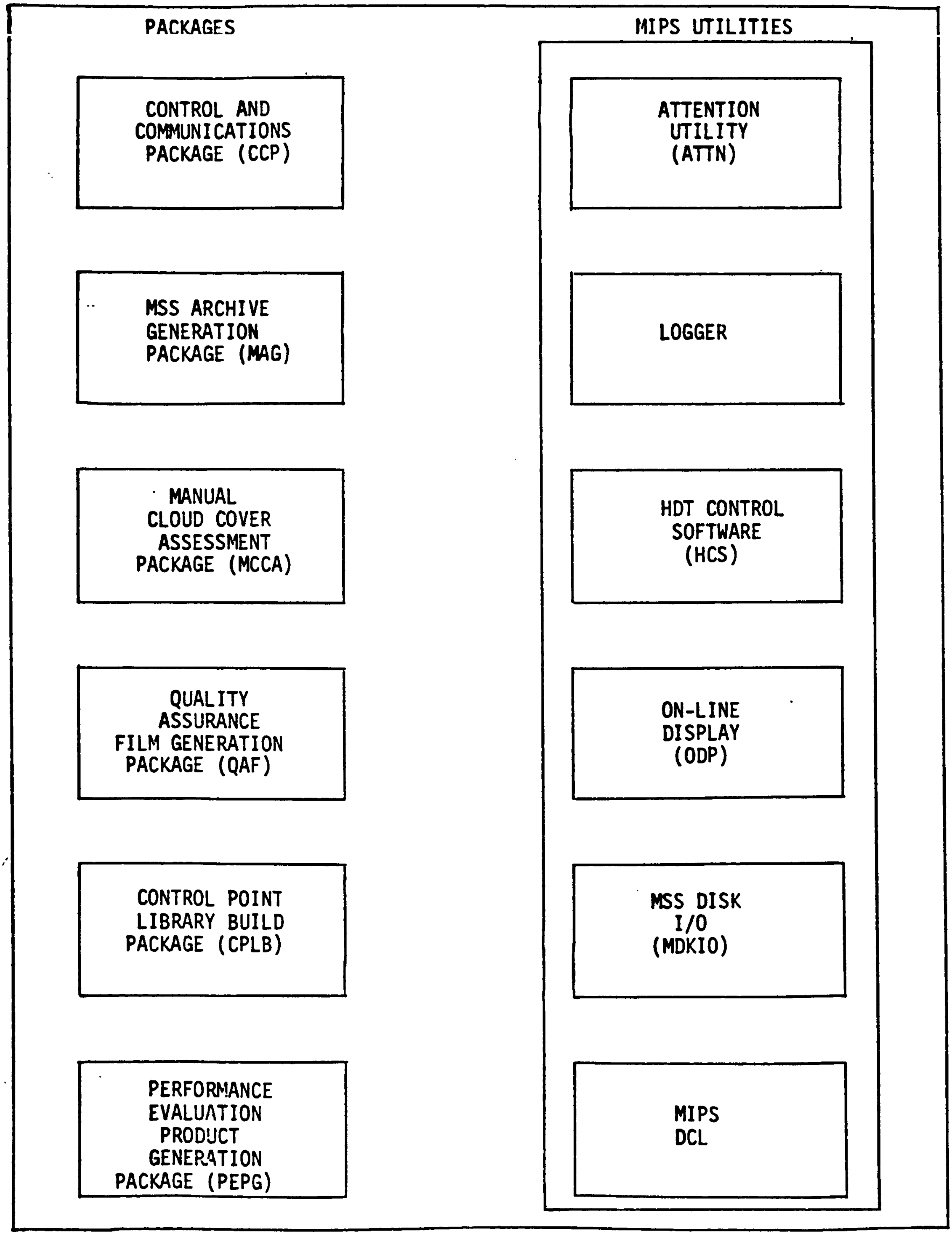

Figure 6.4-3. MIPS Software Structure

6.4.2.1.2 MSS Archive Generation

The MSS Archive Generation Package process includes the following major functions:

a. The image data ingest function provides the capability to input image data from unprocessed high density tapes and store it on disk.

b. The data extraction function extracts control point neighborhoods, calibration wedge values, and histograms for the geometric correction and radiometric correction data processing functions. It also extracts subsampled image data for use by the MCCA and QA functions.

c. The radiometric correction data generation function generates radiometric look-up tables.

d. The geometric correction function, utilizing perturbations computed by the payload correction function, generates geometric correction data. Both systematic correction, taking into account only spacecraft position and attitude, and corrections using control points from the Control Point Library may be produced.

e. The ancillary data processing function formats header, annotation, ancillary and trailer data.

f. The HDT-AM output function controls writing the image and other data.

6.4.2.1.3 MSS Performance Evaluation Product Generation

The MSS Performance Evaluation Product Generation (PEPG) Package contains several major functions:

a. The image data ingest function provides the capability to input image data, from various magnetic tape medium, and temporarily store it on disk.

b. The geometric correction function provides the processing required to prepare a corrected CCT product.

c. The Comtal display function provides the capability to display a selected scene or portions thereof on a Comtal video display.

d. The performance evaluation report function provides results of performance evaluation of functional capabilities including scene comparison, radiometric and geometric correction verification.

6.4.2.1.4 MSS Control Point Library Build

The MSS Library Build software assists the MIPS operator in the selection of control points to be sent to the MMF for placement into the Control Point Library.

6.4.2.1.5 MSS Quality Assurance Film Generation Package (QAF)

The QAF package allows production of 70 mm latent film images of a single selected band from each scene recorded on an HDT-AM during archive tape generation.

6.4.2.1.6 Manual Cloud Cover Assessment Package (MCCA)

The MCCA package allows an operator to view subsampled images on a Comtal image display unit from up to two bands of each scene and to then enter estimates of the percentage of cloud cover for each of four quadrants.

6.4.2.1.7 MIPS Applications Utilities

This is a set of utility software functions that are used by the major software programs.

6.4.2.2 Vendor Supplied Software

Vendor supplied software was supplied by two vendors: Digital Equipment Corporation (DEC) and Floating Point Systems, Inc. (FPS).

Three major packages of software were purchased from DEC to support the MIPS. They are the VAX/VMS Operating System including all of the associated support software, the Fortran IV Plus compiler along with all of the associated library functions, and finally, the DECNET Communication software.

Four major packages of software were purchased from FPS to support the AP-180 Array Processor. They are the software to support DEC VMS along with all associated support software, the software necessary to write and debug assembly language programs, the AP math library software and the software containing Fortran callable routines which perform various image processing functions on the AP-180.

6.4.2.3 System Support Software

Software programs (drivers) not connected with specific application packages were developed to control special designed hardware peripherals used in the MIPS strings. Associated with each driver is a program to exercise the driver and the hardware. The exercisers are not designed for hardware diagnostics, although in most instances they were useful for limited functional testing.

In addition, primitive device drivers and exercisers were developed for each of the basic interfaces used in the MIPS string. These devices are the DR11-C, DR11-B, DR70 and the GE-built special peripheral interface (SPI). These primitives allowed the demonstration of the most basic communication capabilities of the device. The primitives were developed first, before the full drivers and exercisers were written. This allowed easier integration of hardware and software by eliminating complex user, operating system and driver software from a new device.

6.4.2.4 MIPS Production Parameter Files

A parameter is a constant that is widely used throughout MIPS, or a variable whose value determines or restricts the operation of the MIPS software. MIPS provides for changing parameter values. Parameters must be updated from time to time to correspond to changes in the Flight Segment. These changes are brought about by gradually changing conditions, such as sensor degradation, Earth magnetic field changes, or mission events, such as orbit adjustments.

Most of the MIPS parameters affect the image data processed by MIPS in some way and are identified as production parameters. Other parameters that do not affect the image data but do control the efficiency of MIPS operation are classed as operational parameters. The operator may alter operational parameters to improve system efficiency without concern for degrading the quality of the image products. Changes to the production parameters, however, must be made with care, since the quality of the image data changes accordingly. To distinguish the production parameters from the operational parameters, the parameters are stored in separate files.

MIPS production parameters and their history are maintained by the MMF. The MMF transfers these parameter files over DECNET or by using the CCT backup to DECNET. The operational parameters are maintained locally on the MIPS string and are transparent to the MMF.

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6.5 TM IMAGE PROCESSING SYSTEM

The TM Image Processing System (TIPS) performance and production requirements are shown in Tables 6.5-1 and 6.5-2, respectively. The overall processing hardware is shown in Figure 6.5-1 and the flow is shown in Figure 6.5-2.

The input to the TIPS is a 28-track high density tape (HDT-RT) that was either recorded in DRRTS or received from another NASA or Canadian station. Computations are made for geometry, radiometry and annotations. These are written to a 28-track archival tape (HDT-AT), which can be subsequently selected for further processing of one or more scenes through TIPS to generate 241 mm film, CCT-ATs and CCT-PTs.

Designs for this system underwent four revisions after the original proposal was made in October 1977. They are identified as VAX Upgrade System (December 1978), FFP Decom System (February 1980), Jitter System (May 1980) and the current Rebaseline System in September 1980.

The TIPS rebaseline system defined in September 1980 was the system built and delivered to NOAA in September 1984. The functions, hardware and software of that system are described in the following paragraphs.

TM Payload Correction

The TM Payload Correction Subsystem (PCS) processes payload correction data (PCD) downlinked by the Landsat Flight Segment to produce systematic correction functions that correct for known errors in the imagery. In this section, PCD specifically refers to the data contained in the 32K bit/second Q-channel telemetry output by the Landsat Flight Segment.

PCS is performed in two phases. This is because the PCD must be accompanied by the mirror scan correction data extracted from the corresponding TM image data in order to be fully processed. The two data streams are received over different paths, and may be acquired by the Ground Segment at different times. Phase 1 processes the acquired PCD as much as possible without the

Table 6.5-1. TIPS Performance Requirements

REQUIREMENT	TM R&D SYSTEM JULY 31, 1983	TM BASELINE SYSTEM SEPTEMBER 1, 1984
TURNAROUND TIME	48 HOURS MAXIMUM ● RAW DATA TO - PRODUCT HIGH DENSITY TAPE - PRODUCT FILM - CCT	48 HOURS MAXIMUM ● RAW DATA TO - PRODUCT HIGH DENSITY TAPE - PRODUCT FILM - CCT
MAXIMUM UTILIZATION	85% OF 8 HOUR DAY	85% OF 24 HOUR DAY
RADIOMETRIC ACCURACY	±1 QUANTUM LEVEL	±1 QUANTUM LEVEL
MAP PROJECTIONS	SPACE OBLIQUE MERCATOR UNIVERSAL TRANSVERSE MERCATOR/POLAR STEREOGRAPHIC	SPACE OBLIQUE MERCATOR UNIVERSAL TRANSVERSE MERCATOR/POLAR STEREOGRAPHIC
RESAMPLING ALGORITHMS	CUBIC CONVOLUTION NEAREST NEIGHBOR	CUBIC CONVOLUTION NEAREST NEIGHBOR
GEOMETRIC ACCURACY*		
● TEMPORAL REGISTRATION	0.3 PIXEL ** (90% OF THE TIME)	0.3 PIXEL (90% OF THE TIME)
● GEODETIC	0.5 PIXEL ** (90% OF THE TIME) ** WITH APRIORI JITTER CORRECTION	0.5 PIXEL (90% OF THE TIME)

* WITH SUFFICIENT CORRECTABLE GROUND CONTROL POINTS

Table 6.5-2. TIPS Production Requirements

OUTPUT	NAME	USE	VOLUME (SCENES/DAY)	
			R&D PERIOD JULY 31, 1983	NOAA OPERATIONS SEPTEMBER 1, 1984
HIGH DENSITY TAPE - ARCHIVAL	HDT-AT	ARCHIVAL PRODUCT & LAS	12	100
HIGH DENSITY TAPE - PRODUCT	HDT-PT	INITIAL PRODUCT & LAS	12	50
COMPUTER COMPATIBLE TAPE - ARCHIVAL	CCT-AT	USER PRODUCT, PERFORMANCE EVALUATION & LAS	TOTAL OF 2	TOTAL OF 10
COMPUTER COMPATIBLE TAPE - PRODUCT	CCT-PT	USER PRODUCT, PERFORMANCE EVALUATION & LAS		
241 MM FILM - PRODUCT	F241-PT	USER PRODUCT & PERFORMANCE EVALUATION	12	50
70 MM FILM - ARCHIVAL	F70-AT	PERFORMANCE EVALUATION	12 (IN 2 BANDS)	100 (IN 2 BANDS)
CONTROL POINT LIBRARY	CP CHIPS	GEODETIC CORRECTION	50	100

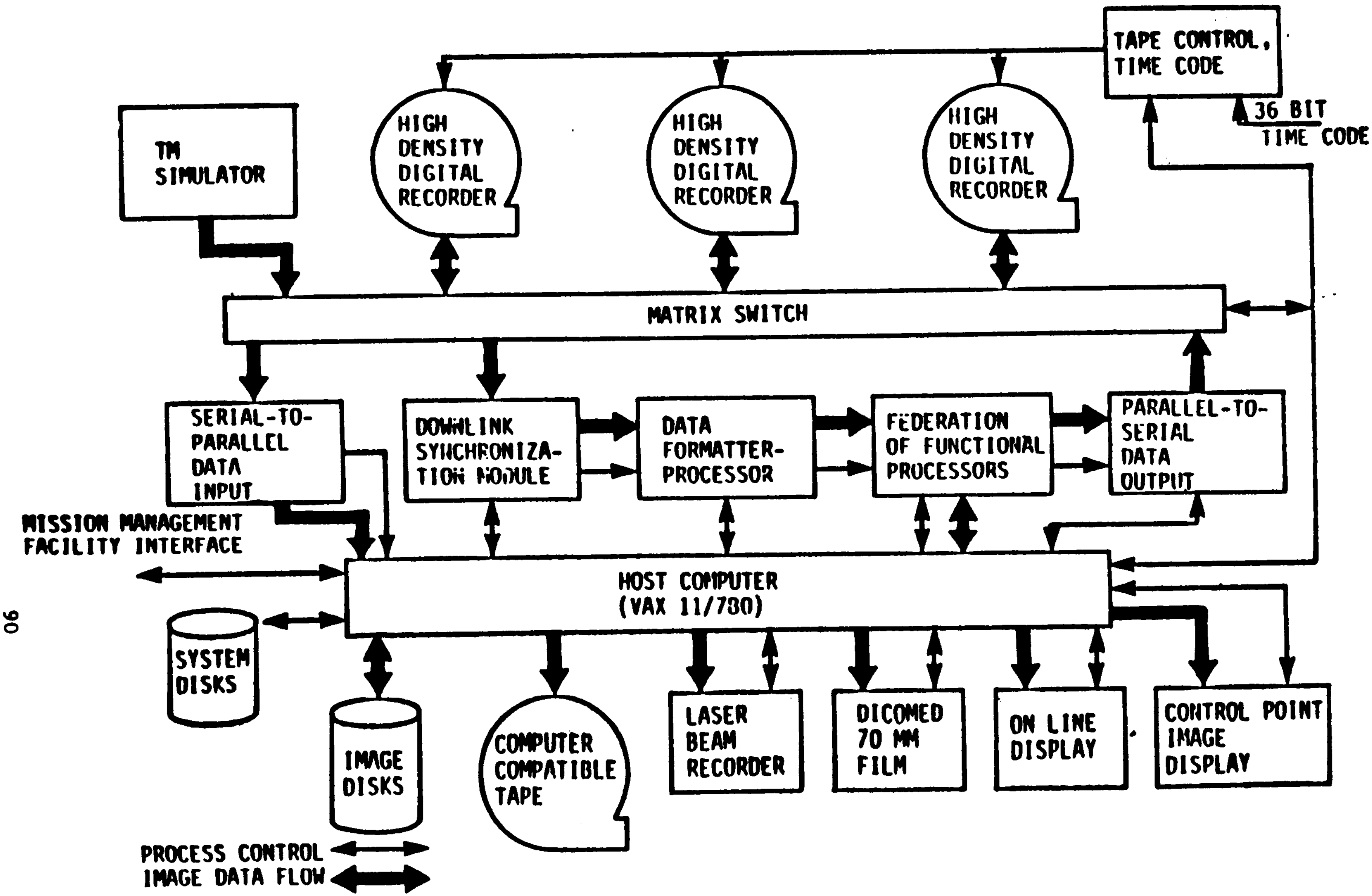
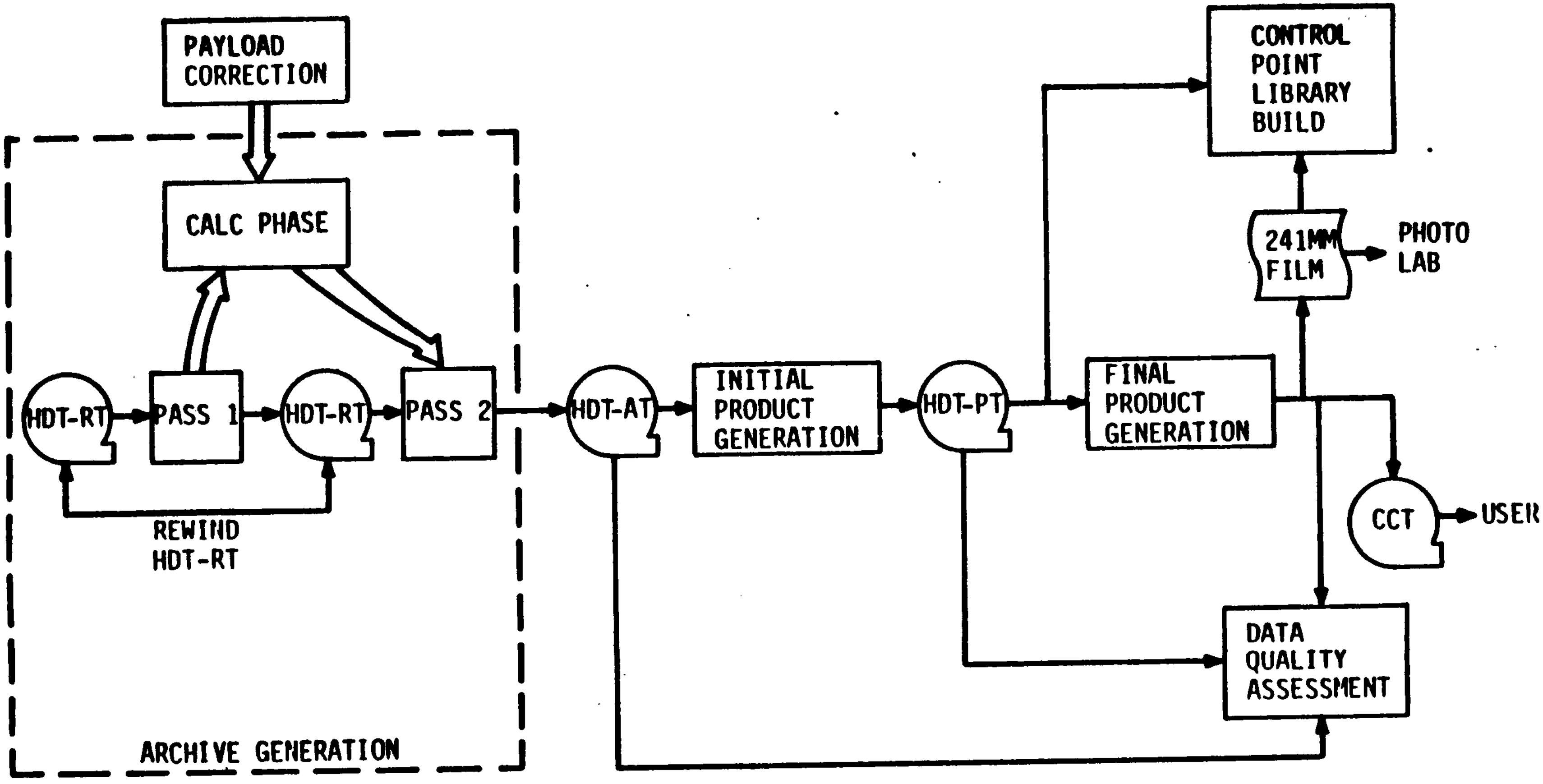


Figure 6.5-1. TIPS Hardware Architecture



LEGEND:

CCT : COMPUTER COMPATIBLE TAPE
HDT-AT: TM ARCHIVAL HIGH DENSITY TAPE
HDT-PT: TM PRODUCT HIGH DENSITY TAPE
HDT-RT: TM RAW HIGH DENSITY TAPE

Figure 6.5-2. TIPS Processing Architecture - TIPS Process Flow mirror scan correction data. Phase 2 completes the processing when the mirror scan correction data is available.

PCS Phase 1

TM telemetry data (32 bit/second, Q-channel telemetry) is acquired from the Flight Segment via Nascom by the CSF. The CSF extracts the necessary data, packages it, and routes it to Phase 1, via CCT post acquisition. PCS Phase 1 performs the following processing:

a. Calibration, validation, enhancement and smoothing of the PCD.
b. Determines modes.
c. Filters, interpolates, and combines ADS and DRIRU samples into a coherent attitude estimate.
d. Models the ephemeris data based on a simplified orbit model and propagates least squared error ephemeris estimates.

The output is a time-ordered sequence of Flight Segment attitude estimates, ECI ephemeris estimates and TM instrument modes, for TM instrument operational periods. This data is saved as processed TM payload correction data (PCD), to await extraction of the corresponding intervals of mirror scan correction data.

PCS - Phase 2

When mirror scan correction data is available, Phase 2 completes processing the processed TM PCD. PC Phase 2 generates systematic correction functions that correct for known errors in the image data. These functions incorporate corrections for:

a. Detector to detector misregistration
b. Band to band misregistration
c. Sensor misalignment
d. Knowledge of ephemeris
e. Knowledge of attitude
f. Non-linear mirror profile
g. Earth rotation
h. Map projection

i. Jitter

j. Scan line corrector nonlinearity.

TM Archive Generation (TAG)

When TM system correction functions are available for imagery acquired on HDT-RT, TM archive generation (TAG) may proceed.

TAG Preprocessing Calculations

TAG preprocessing computes the locations of CPNs in line and pixel coordinates (the locations are supplied in coordinates of latitude and longitude).

TAG First HDT Data Pass (Pass 1)

The TAG First HDT Data Pass extracts data from the HDT-RT for use in subsequent processing. TAG Pass 1 extracts TM radiometric calibration data and histograms of the TM scene data. TAG Pass 1 extracts neighborhoods about the expected locations of control points in the TM scene data, called Control Point Neighborhoods (CPNs). TAG Pass 1 extracts mirror scan start time, line length and quality information from every line of TM data. TAG Pass 1 extracts subsampled image data, in several bands, from the TM image data.

TAG Calculations Phase (CALC)

For the data extracted by Pass 1, TAG CALC phase performs the following processing:

a. Radiometric function calculation

b. Control point neighborhood processing

c. Geodetic correction improvement

d. HAAT and line support data generation.

The CALC phase calculates radiometric correction functions from the TM radiometric calibration data and histograms of the TM scene data. TAG CALC phase performs control point neighborhood processing on the extracted CPNs. The CALC phase optionally uses the extracted CPNs and control point chips to improve the accuracy of the system correction data produced by PCS. Finally, the CALC phase generates radiometric correction lookup tables, header, ancillary, annotation and trailer (HAAT) data and line support data for the HDT-AT.

TAG Second HDT Pass (Pass 2)

The Second TAG HDT Pass (Pass 2) generates the HDT-AT tape. For each interval of data to input on HDT-RT, TAG Pass 2 copies the HAAT section to HDT-AT, then inputs the raw data from the HDT-RT and performs the following processing. Pass 2 radiometrically corrects the raw data by applying the appropriate radiometric correction lookup table, reformats the data from BIP to BIL, and writes the data to HDT-AT. During this pass, TAG also extracts neighborhoods about the expected locations of candidate control points and subsampled image data.

Cloud Cover Assessment (CCA)

TAG Cloud Cover Assessment operates in two modes - interactive and automatic. In interactive mode, CCA displays framed images of subsampled image data extracted by TAG to an operator, and accepts an operator estimate of cloud cover for each quadrant of the displayed image. In automatic mode, CCA calculates cloud cover estimates for the TM scene data by applying an assessment algorithm to the subsampled image data extracted by TAG.

70 mm Film Generation

This function accepts data sets containing subsampled TM imagery generated by TAG and generates a 70 mm film product. Each input scene is reformatted to band-oriented format and output to a film image on a film roll. The images are gridded, annotated and partially geometrically corrected, with fixed corrections.

TM Initial Product Generation

This function generates an HDT-PM containing geometrically corrected image data in one of three map projections. The input to this function is an HDT-AT containing radiometrically corrected image data and geometric correction information. The geometric correction is accomplished by reading the information from the HDT-AT and using the geometric correction operator in the

FFP to resample the image data. Both cubic convolution and nearest neighbor resampling algorithms are available. This function must also convert the image data from BIL format to BSQ format.

TM Final Product Generation

This function generates 241 mm film or 1600/6250 bpi computer compatible tapes from an HDT-PT or from an HDT-AT. CCT products may be in either BSQ or BIL format. Either full scenes or quadrants may be available on CCTs and all quadrant scenes are digitally mosaicable.

TM Data Quality Assessment

TM Data Quality Assessment allows any TM digital product to be read and evaluated.

TM Control Point Library Build (TCL)

TM Control Point Library Build accepts an HDT-PT (and directory) and a candidate control point list, and extracts the required scenes from the HDT-PT. At this point, TCL operates in two different modes, depending on the type of the eventual control point (geodetic or relative). For each candidate geodetic control point, TCL interactively displays the associated CPN to an operator. The operator views the CPN along with the corresponding map marked with the control point location, through a zoom transfer scope. The operator transfers the control point location marked on the mp to the CPN image display. The operator interacts with TCL in this fashion to designate control point locations for an interval related data set. TCL then filters the control point locations for the data set to reject outlier points, extracts chips and auto-correlates them to determine their suitability for registration, and generates requests to update TM control point library entries for the original candidate control points. The update request either enters the designated control point chip into the library, or specifies a reject code (e.g., poor suitability).

For each candidate relative control point, TCL calculates the location of the relative control point in the control point neighborhood, and interactively displays the associated CPN to an operator. The registration control point chip is indicated by a visible box on the display. The operator may elect to accept or reject the chip, or may move the registration control point. If the operator accepts the chip, TCL performs processing similar to that described above to include the chip in the library. If the operator rejects the chip, TCL specifies a reject code in the update request (similar to above). If the operator moves the registration control point, TCL continues as above, from the point where the chip is indicated by a visible box on the display.

6.5.1 HARDWARE DEVELOPMENT

The system and image disks are DEC RP06, 176 Mbyte, 806 Kbyte/sec disk drives. There are three system and ten image disks per string.

The host computer is a VAX 11/780 with five megabytes of main memory, eight massbusses and a floating point accelerator.

The computer compatible tapes are standard 9-track tapes with 1600/6250 bpi densities and record speeds of 125 ips.

The Goodyear laser beam recorder records images on 241 mm film at a rate of up to 2 Mpixels/sec. Photo IX shows the laser beam recorder.

The Dicomed 70 mm film recorder converts digitally encoded TM data to high resolution (70 mm) photographic film.

The TIPS system uses Comtal 512 x 512 pixel displays. These displays are used to verify system performance, examine image quality, assess cloud cover and select and designate control points.

The SPDI accepts formatted serial data from the playback of high density tapes, performs frame synchronization on the data, and strips out and reformats this data into parallel words for transfer to the VAX.

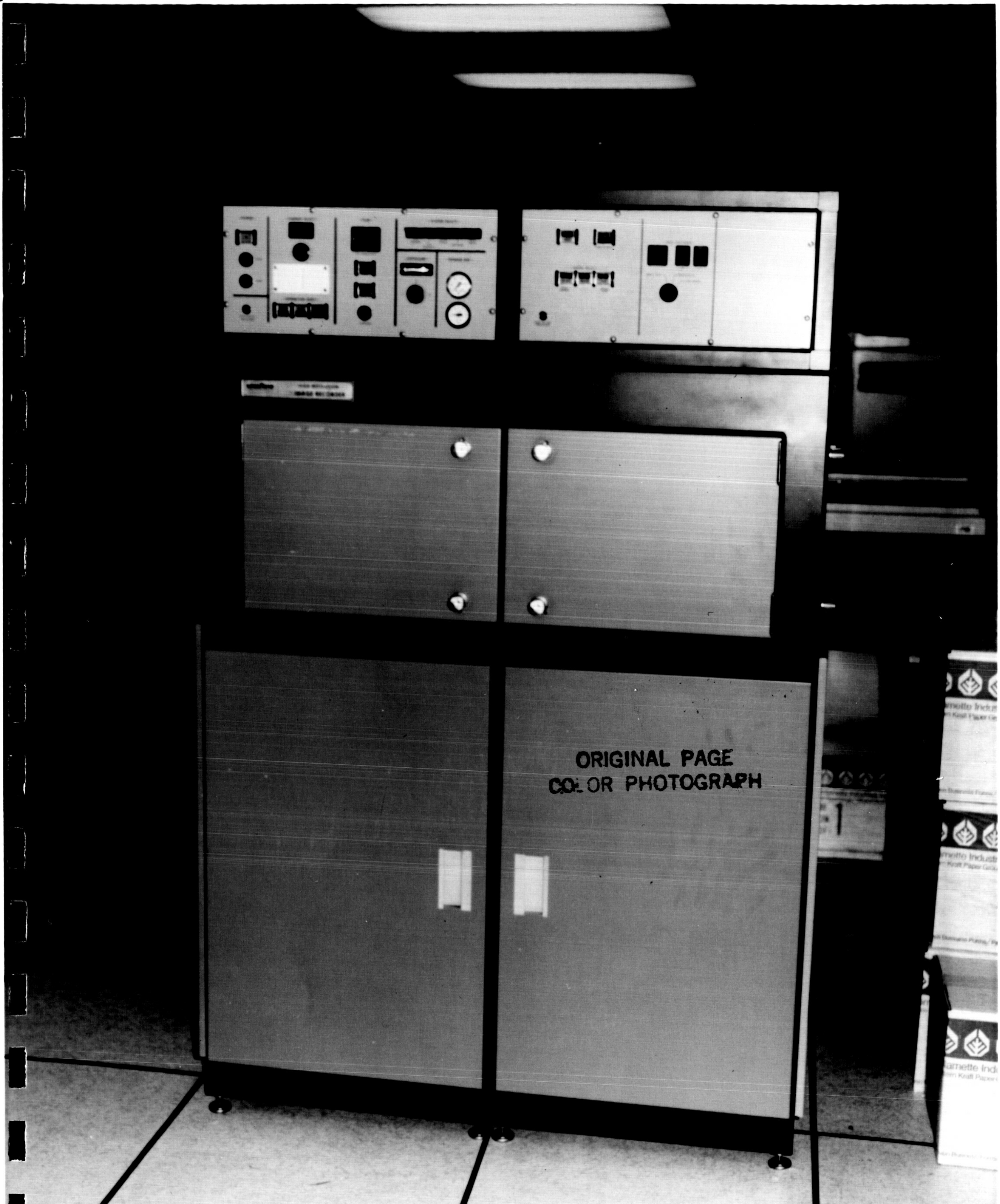


PHOTO IX. IGF LASER BEAM RECORDER

The DSM inputs TM data in sensor format and performs data stream synchronization, data extraction and data quality monitoring. The DSM outputs synchronized image, scan and quality data.

The DFP inputs synchronized unprocessed TM scan data from the DSM and performs high speed pixel oriented processing and formatting functions. Partially decommutated scan data is output to the FFP while histograms are output to the VAX 11/780 or radiometric lookup tables are received from the VAX 11/780.

The FFP is a high speed pipelined data processor used for data decommutation, correlation and geometric correction. In the data decommutation mode the FFP inputs partially decommutated scan data from the DFP and outputs fully decommutated data to the PSDO. In the correction mode the FFP inputs uncorrected control point neighborhoods and fully corrected control point chips from the VAX and outputs the correlation surface. In the geometric correction mode the FFP inputs uncorrected data and outputs geometrically corrected data.

The PSDO accepts 32 bit parallel data from the FFP, reformats the data into major and minor frames and outputs a formatted serial bit stream to be recorded upon high density tapes.

The matrix switch inputs digital data from the PSDO TM simulator on HDDRs and outputs digital data to the SPDI, DSM or an HDDR.

The HDDRs are 28-track 33 Kbpi high density recorders used for inputting and outputting image data. The bit rates used in TIPS range from 2.8 Mbps to 42.453 Mbps.

6.5.2 SOFTWARE DEVELOPMENT

The TIPS software structure shown in Figure 6.5-3 logically grouped functions and allowed for separate software development teams. The bulk of the TIPS software was written in Fortran. It consisted of approximately 268,000 lines of code.

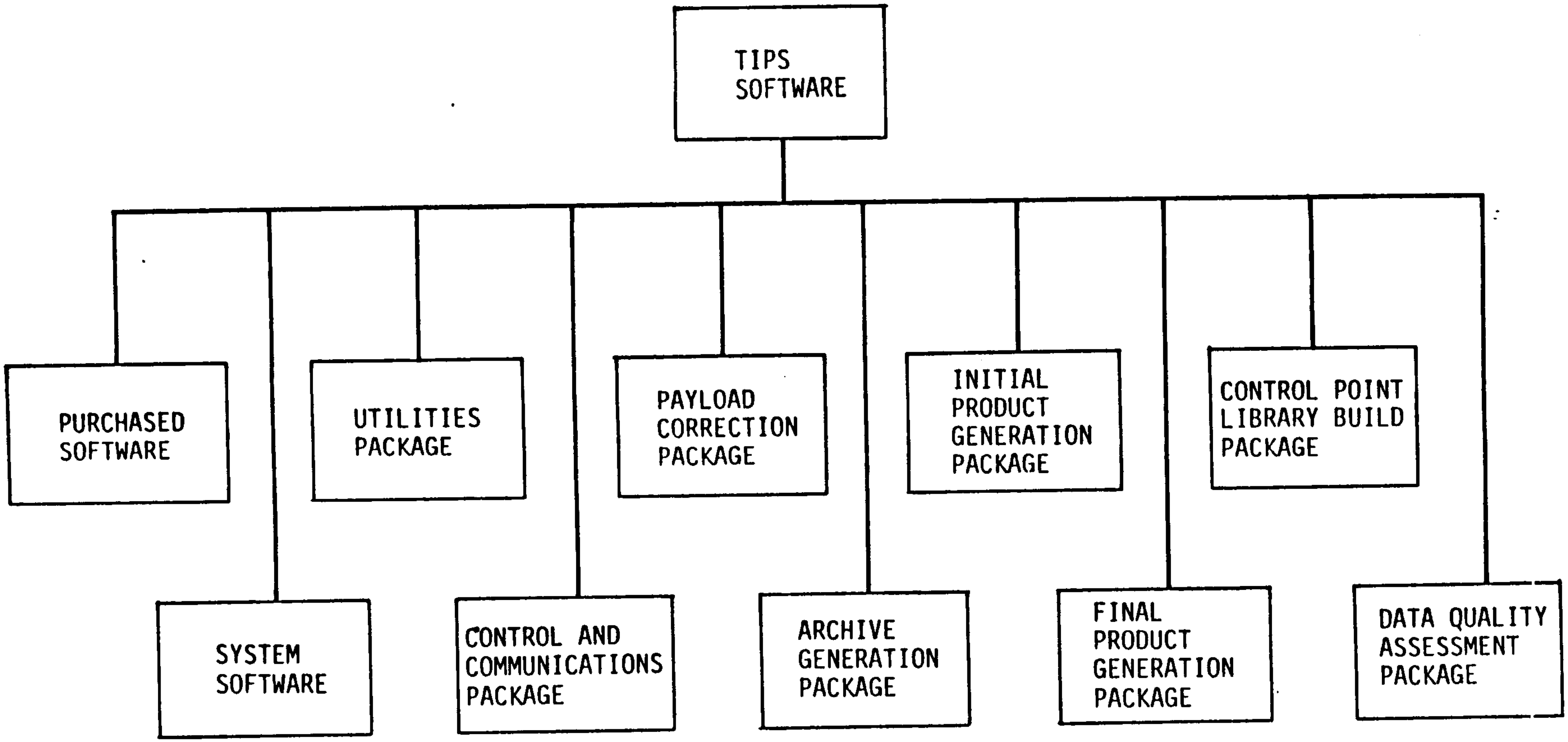


Figure 6.5-3. TIPS Software Structure

Three different kinds of software were utilized in TIPS: applications software, developed by GE, vendor-supplied software, and system software, developed by GE to support non-standard peripheral devices.

Additionally, parameter files were designed and used to supply values of time variant and invariant constants.

6.5.2.1 Applications Software

6.5.2.1.1 TM Control and Communication

For each major TIPS function, a number of controlling functions are required that are identical. To reduce software redundancy, most of these operations are removed from the TIPS functions of which they are a part and are allocated to a single package called the TM control and communication (TCC) package. A copy of the TCC package software executes on each TIPS string. Each copy executes independently, with no interface with the other copies. The TCC fulfills three classes of requirements. These requirements can be categorized as: MMF-T communication, string control, and work item handling.

6.5.2.1.2 TM Payload Correction Subsystem

The PCS processes telemetry data to produce geometric correction functions that correct for systematic errors in the imagery. This process is performed on the DEC 2060. It involves the smoothing, validating and propagating of both the attitude and ephemeris data followed by the generation of systematic correction data.

6.5.2.1.3 TM Archive Product Generation

The TM archive product generation (TAG) software performs the function of ingesting raw TM imagery intervals from an HDT-RT through the DSM/DFP/FFP, and outputting radiometrically corrected imagery to an HDT-AT through the PSDO. The TAG software performs its function based on a TAG work order received from TCC. Secondary functions of the TAG software provide for display of the imagery during processing, generation of geometric/geodetic correction data, maintenance of quality indicators, subsampling of imagery for 70 mm film production, and manual and automatic cloud cover assessment of ingested scenes.

6.5.2.1.4 TM Initial Product Generation

The TM initial product generation (TIG) software performs the function of ingesting radiometrically corrected imagery in BIL format and its corresponding geodetic correction data on an HDT-AT through the SPDI, and outputting geodetically corrected imagery in BSQ format to an HDT-PT through the PSDO. The TIG software performs its function based on a TIG work order received from the TCC. TIG provides for display of the processed imagery during pipeline operation and maintenance of quality indicators.

6.5.2.1.5 TM Final Product Generation

The TM final product generation (TFG) software provides for generation of end user products from either an HDT-AT or an HDT-PT. Final products are provided for a requested scene as either CCTs or 241mm film. The TFG software performs its function based on a TFG work order received from the TCC. The high density tapes are ingested under software control through the SPDI and output to either a CCT or the Laser Beam Recorder (LBR) for film output. TFG provides for display of imagery during processing and maintenance of quality indicators.

6.5.2.1.6 TM Control Point Library Build

The TM control point library build (TCL) software provides for ingest of imagery from an HDT-PT, extraction of control point neighborhoods (CPN) and operator designation of candidate geodetic control points within the neighborhoods. Control point chips are extracted from the CPNs for inclusion in the control point library used for geodetic correction computations in TAG. The TCL also provides for digitization of candidate control points using a reference map to specify known locations in terms of latitude and longitude around the desired control point for subsequent selection of candidate CPN imagery extraction areas.

6.5.2.1.7 TM Quality Assurance Film Generation

The TM quality assurance film generation (TQF) package produces 70 mm latent film images from selected bands of imagery for each scene recorded on an HDT AT during TAG.

6.5.2.1.8 TM Data Quality Assurance

TM data quality assurance (TDQ) software permits post-product quality checks. TDQ provides for format checks, dumps and displays of reingested HDT and CCT products. Quality reports summarize the results of the quality check(s) performed.

6.5.2.1.9 TIPS Utility Library

The TIPS utility library contains software that performs functions common to many parts of TIPS.

6.5.2.2 Purchased Software

This paragraph describes the pieces of software that were procured from outside sources to support the development of TIPS. This software was supplied by two sources:

a. Digital Equipment Corporation (DEC)
b. General Electric, Electronic Systems Division (Syracuse).

Digital Equipment Corporation Supplied Software

Three major packages of software were purchased from DEC to support TIPS. They are:

a. VAX/VMS Operating System, including all of the associated support software.
b. The Fortran-IV Plus compiler, along with all of the associated library functions.
c. Decnet communications software.

General Electric, Electronic Systems Division Supplied Software

One major package was acquired from the General Electric Company Electronic Systems Division. This package consists of support software for the FFP. The components of this software are:

a. Host Computer Software for the PDP-11/70
b. DDP Resident Software
c. System Control Terminal Software.

6.5.2.3 System Support Software

Software programs not connected with specific application packages are developed to control special designed hardware peripherals used in the TIPS strings. Associated with each driver is a program to exercise the driver and the hardware. The exerciser is not designed for hardware diagnostics, although in some instances it may be of limited use in this area.

Photo X is a sample of the finished 241 mm product.

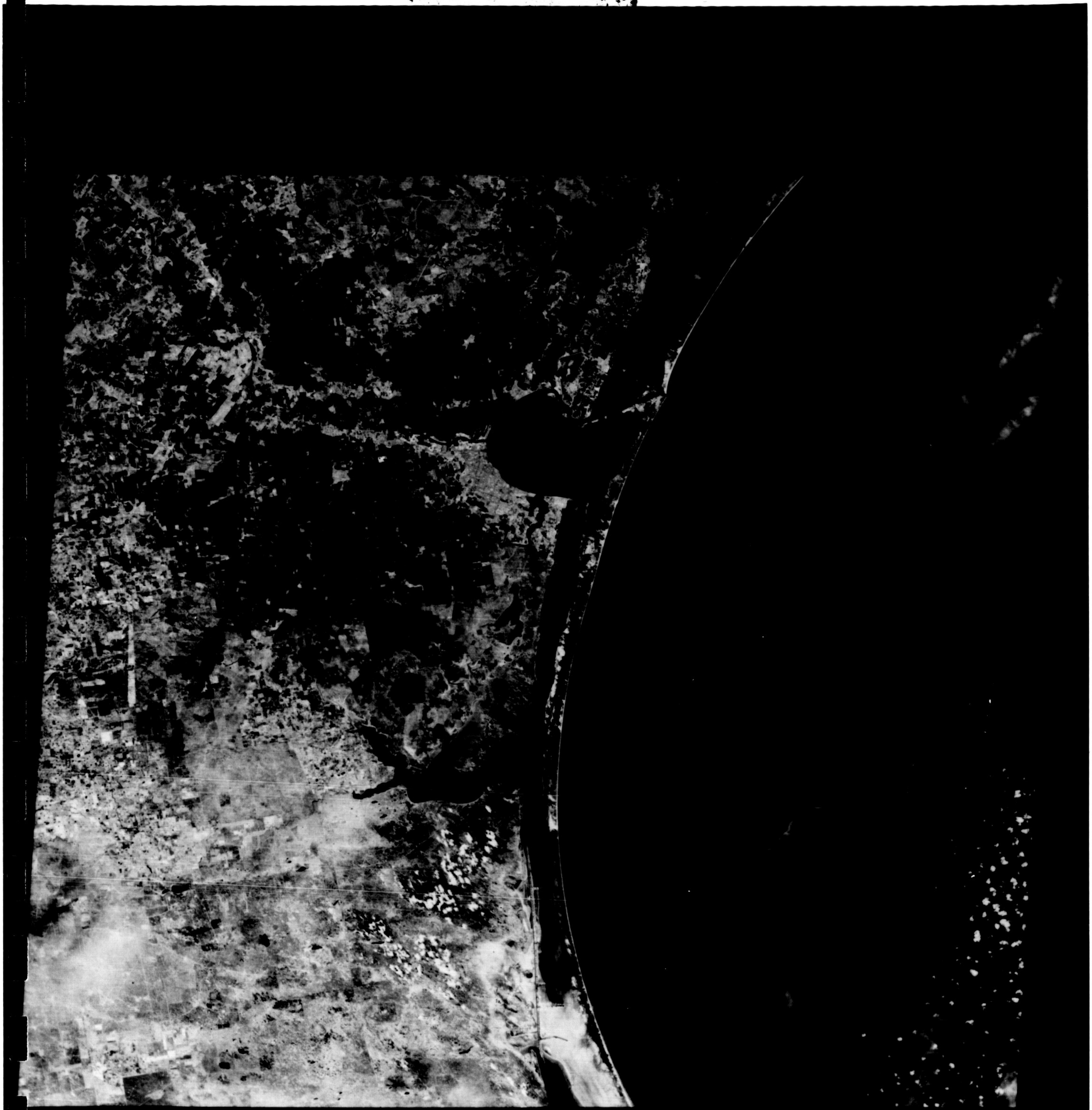


PHOTO X. TM IMAGE OF CORPUS CHRISTI, TEXAS

6.6 TRANSPORTABLE GROUND STATION

This section traces the history and evolution of the Transportable Ground Station (TGS) from the proposal stage through to its current configuration. Its overall performance is evaluated and, in paragraph 6.11.2, the lessons learned from its implementation are identified.

6.6.1 FUNCTION

The Landsat-D Transportable Ground Station, as specified by the RFP and defined in the General Electric Technical Proposal, is a receive only system. It is capable of acquiring and tracking the Landsat-D series spacecraft and receiving the following spacecraft signals: X-band wideband thematic mapper (TM) and multispectral scanner (MSS) data, S-band wideband MSS data, and S-band narrowband telemetry data. The TGS demodulates and bit synchronizes the received data, and retransmits the data via high speed modems for further processing.

As originally conceived, the TGS function was to evaluate the quality and performance of the Landsat-D series spacecraft direct broadcast links, which were intended primarily for foreign ground station use. TGS also was to serve as a secondary data source of eastern U.S. coverage while installed at the GSFC site. The prime data link for the U.S. data processing system was the Landsat to TDRSS K-band link, TDRSS to White Sands, White Sands to NASA GSFC via Domsat link. The TGS was designed to be transportable to allow the system to be moved, after its initial performance evaluation function was completed, to selected remote sites where special data coverage requirements might exist, or which were in the zone of exclusion of the Landsat/TDRSS system combination. For this purpose, the TGS was designed to be transportable by C-141 type aircraft for installation at a previously prepared site within twenty working days. The requirement was for the system to be capable of disassembly and relocation a minimum of five times within a five year period without major overhaul, modification or performance degradation.

The system proposed consisted of a 10-meter antenna subsystem, an electronics van subsystem, and a boresight test antenna subsystem. Site preparations included a steel reinforced concrete antenna foundation, site survey, a trailer pad, cableways, electrical power and water supply.

The TGS has become, in fact, the primary data acquisition source for Landsat 4 and 5 coverage of the eastern United States, and for the first year after the launch of Landsat 4, the only U.S. source of TM data. It can receive direct Landsat signals out to 3000 kilometers.

6.6.2 SYSTEM CONFIGURATION

The TGS is composed of three subsystems: the 10-meter antenna subsystem, the electronics van subsystem and the boresight subsystem. Figure 6.6-1 is a block diagram of the TGS.

The 10-meter antenna subsystem includes an elevation over azimuth tracking pedestal; a Cassegrain antenna configuration consisting of a 10-meter parabolic reflector, a 60-inch hyperboloid subreflector, a dual quad X- and S-band feed assembly, monopulse comparators, monoscan converters, feed filters, parametric amplifiers, dual channel down-coverters, and test signal injection networks; and an antenna base extension including drive power amplifiers, additional electronics, and an azimuth axis tilt mechanism located at the base extension to pedestal interface. Figure 6.6-2 provides additional details of the antenna configuration.

The electronics van subsystem is a 33-foot commercial air ride trailer that contains the receivers, demodulators, bit synchronizers, data link cable modulators; antenna control servo control unit, and computer; time code receiver and generator; and system test equipment. In addition, the van has expansion space for four additional racks of equipment. The van subsystem includes heating, air conditioning and lighting equipment. Figure 6.6-3 is a floor plan of the van.

The boresight subsystem consists of an X-band antenna and an S-band antenna, both 4 feet in diameter, antenna positioners, a signal source, controller and remote control unit. This equipment provides the capability to checkout,

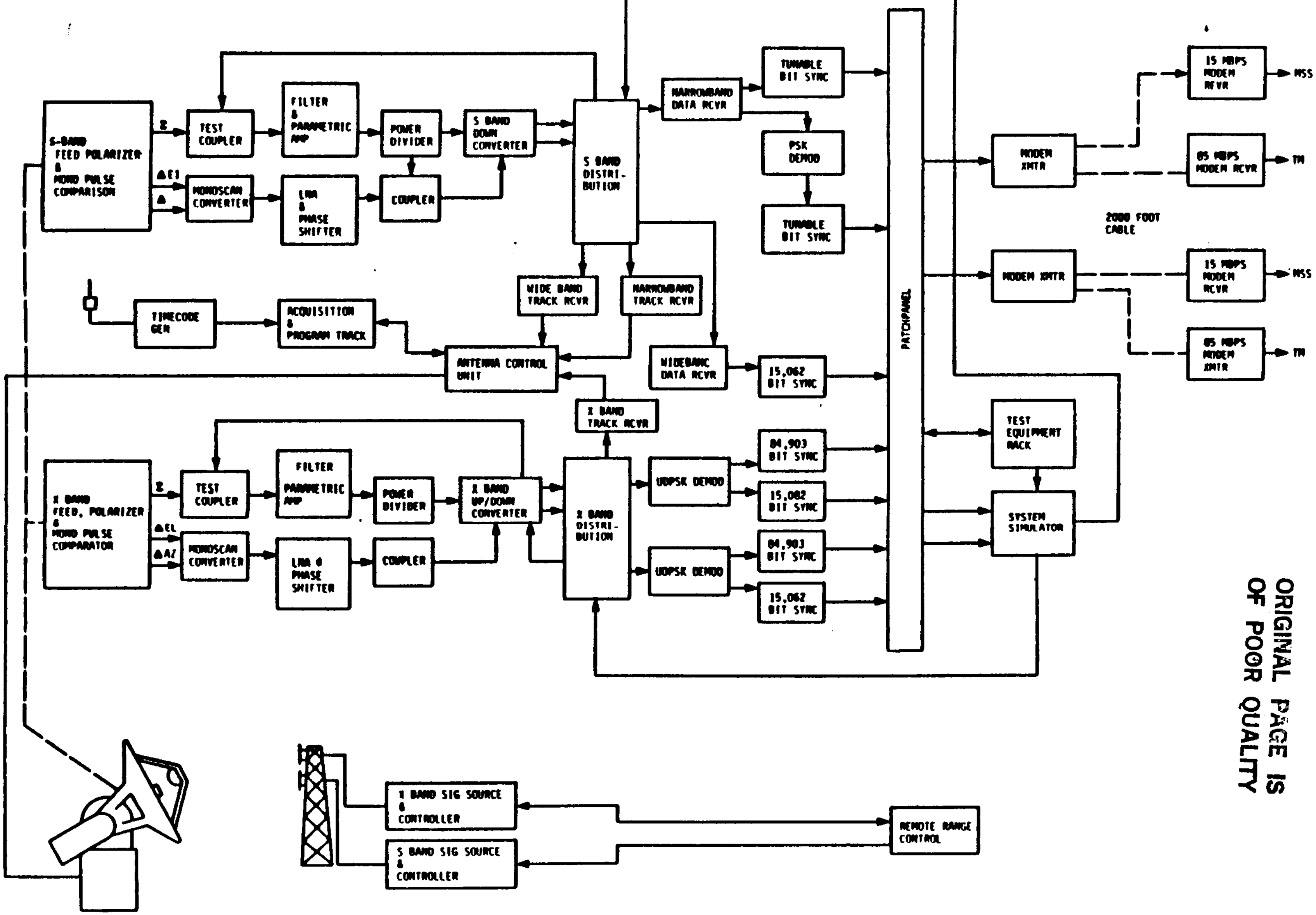


Figure 6.6-1. Transportable Ground Station Block Diagram

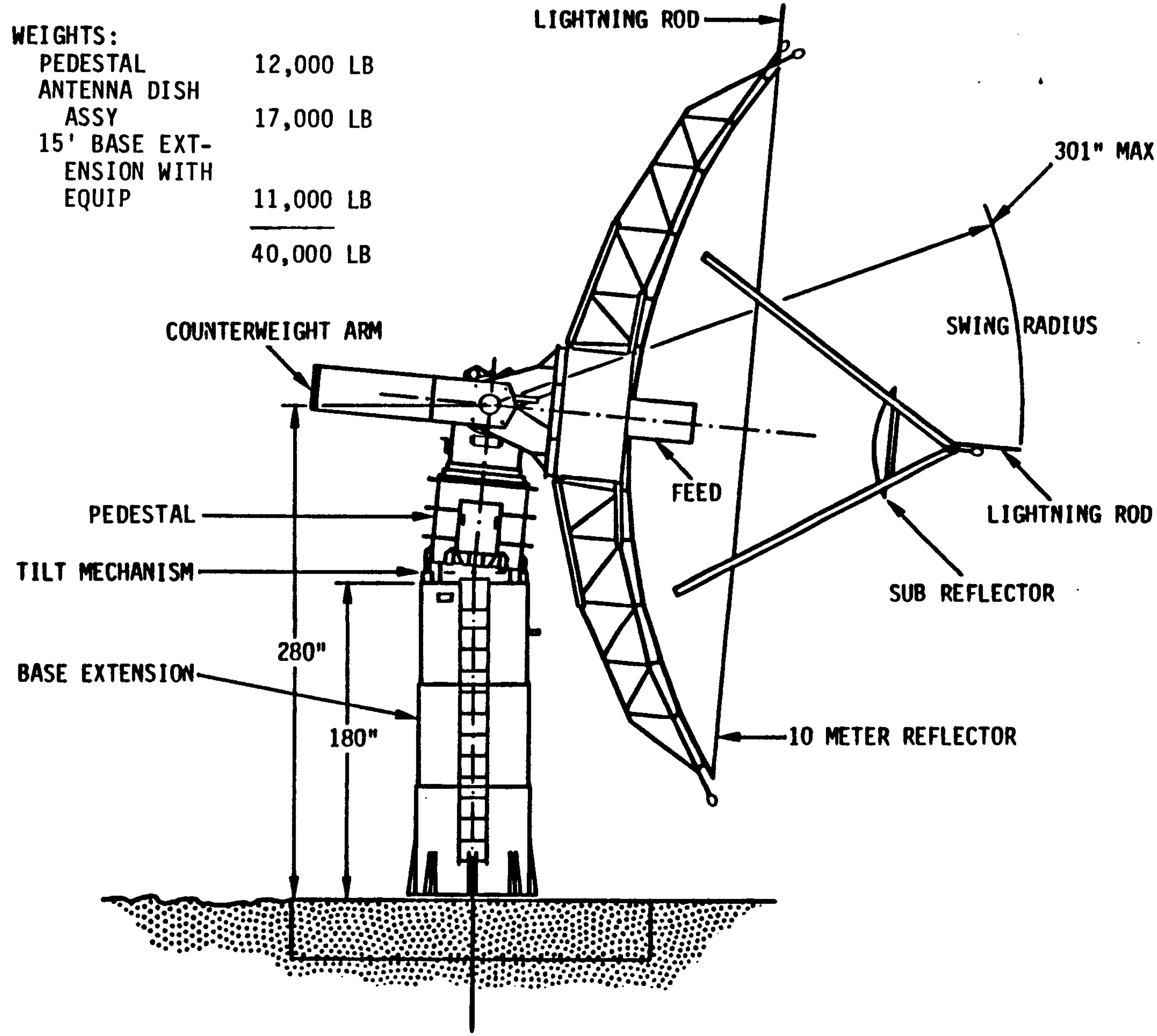


Figure 6.6-2. TGS 10-Meter Antenna

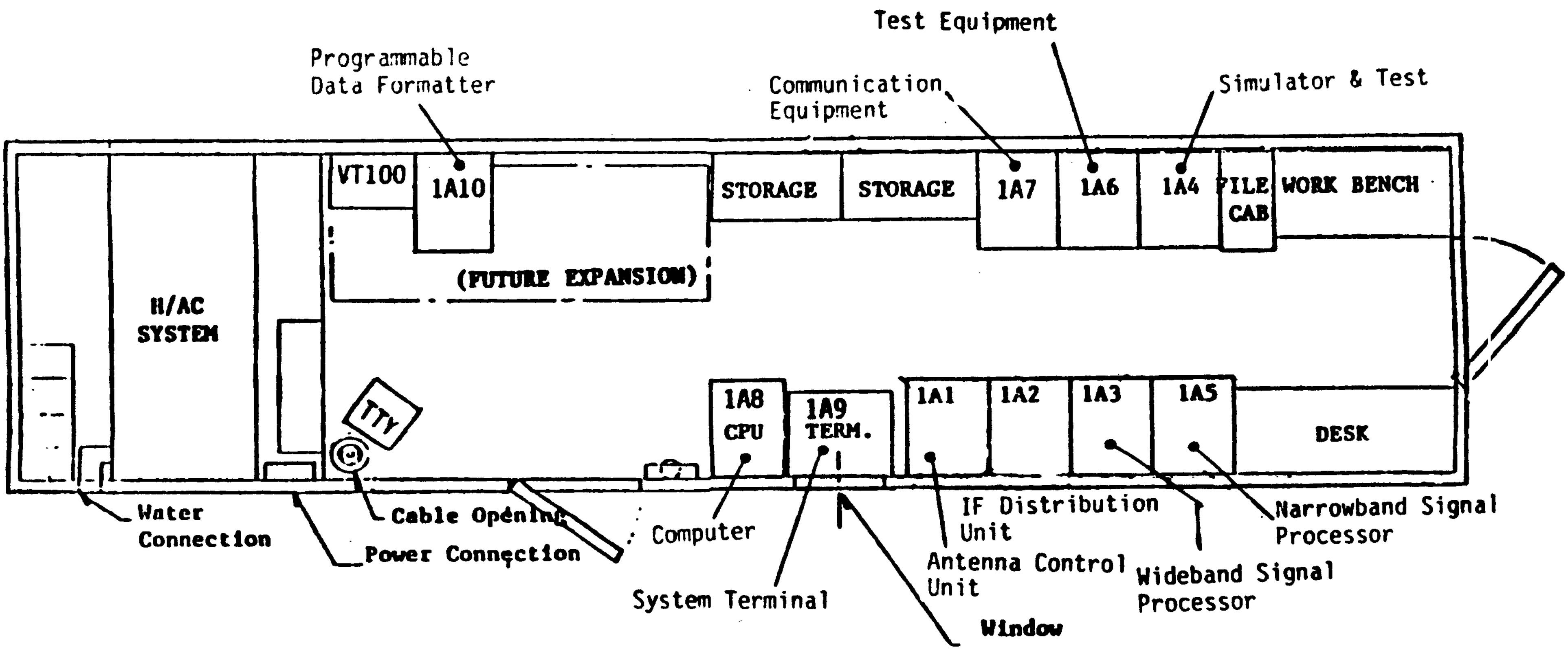


Figure 6.6-3. TGS Van - Floor Plan

adjust and verify the performance of the 10-meter antenna subsystem tracking function.

Specifications for the performance requirements and for the system integration of the TGS were performed by General Electric. The hardware design and fabrication were performed by Scientific Atlanta, Inc., (SA) under subcontract to GE. GE also provided the antenna pointing software with computer and related equipment. Installation and checkout of the system at GSFC was performed by SA and GE. Site preparations were provided by the GSFC Facilities Engineering Division and their subcontractors, based upon facility requirements established by GE. The boresight antennas and signal source equipment were installed on an existing NTTF tower.

6.6.3 IMPLEMENTATION

The delivered system closely matched the proposed design due to the experience of the GE - SA team with similar previous projects. Some of the more notable differences are described in the following paragraphs.

The electronics van length was increased from the proposed 25 feet to 33 feet. This increase in size of the trailer provided additional space required for test equipment, the antenna control computer and terminal, parts and equipment storage, telex machine, and allowed expansion room for future equipment such as tape recorders.

A programmable data formatter (PDF) was added to the TGS in response to Contract Change Notice 86. The PDF provides capability to transmit spacecraft telemetry and payload correction data via a 56-kilobit modem through Nascom to the CSF . The original plan was that NTTF telemetry would be used for data processing and consequently there was no need for the TGS telemetry data at the GSFC location other than for performance monitoring. The TGS provides a greater coverage circle than that available to the NTTF antenna due to less site masking. This resulted in TM scenes for which payload correction data was not locally available. The addition of the PDF simplified data processing by providing telemetry data for all scene data collected by the TGS.

A four-channel strip chart recorder was added to the TGS test equipment complement in response to Contract Change Notice 85. This change allows simultaneous recording of S-band telemetry, S-band wideband data, and X-band receiver AGC signals for operational performance monitoring as well as additional system servo test capability.

A number of enhancements were added to the antenna pointing software during the design and checkout phase. These include servo tests, time code generator interface tests, automatic prepass positioning of the antenna to its center zero, and prepass warning message, to name a few.

6.6.4 PERFORMANCE

Preliminary acceptance test of the TGS was completed at SA on 26 March 1981. The system was installed at GSFC during April 1981, 15 months in advance of the launch of Landsat 4. The installation went smoothly with the exception of the antenna foundation problems noted later in paragraph 6.11.2. During this period, the system was operated with the Landsat 2 and 3 spacecraft. Results of testing and operation verified that all required performance specifications were met or exceeded. The availability of the TGS well in advance of the spacecraft launch permitted extensive checkout of the system and resolution of minor system operational problems, in addition to weeding out early life part failures.

The azimuth axis tilt was set to a predetermined value after installation of the system. The transformation of pedestal coordinates to true coordinates was verified to be accurate using the boresight position, Sun track and satellite track data. Prior to the launch of Landsat 4, the tilt was readjusted to its current value when the spacecraft ground tracks were more accurately defined. Azimuth axis tilt to solve the "keyhole problem" of elevation over azimuth tracking antennas was first used for the TGS antenna. Essentially, the tilt offsets the keyhole (the zenith circle through which the antenna cannot achieve sufficient acceleration and velocity to maintain the spacecraft within the antenna beamwidth) to a position that is between the satellite orbit paths. The fixed offset is an excellent solution for the

Landsat application as the satellite orbits are accurately maintained and the TGS was to be dedicated to tracking of the Landsat series of spacecraft. A variation of this design now uses a motorized tilt mechanism that allows the tilt angle to be adjusted between passes. This approach, based on the TGS design, is applicable to antennas that must track a variety of spacecraft. In addition to solving the X-band keyhole problem, the azimuth axis tilt eliminated the need for a zenith pass programmer, which was the technique previously used to solve the problem at the wider beamwidth of S-band.

Another new design first used on the TGS was the 3-phase, servo power amplifiers. This design was undertaken to eliminate unbalance in the system a.c. power requirements. In addition to improving a.c. loading and regulation, the new design provided greater torque output to the elevation and azimuth drives.

The wideband data link modems designed to transmit TM and MSS data to the DRRTS in Building 28 exceed the system performance requirement error rate of less than one part in 10^7.

The antenna pointing software was specifically designed for the TGS application. Antenna pointing information is calculated by the program prior to the spacecraft pass based upon the improved inter-range vector (I^2RV) data entered by the operator. The program determines all crossings within the station acquisition circle, and calculates the pointing angles in 200 millisecond increments for the selected number of passes. It determines AOS, LOS and highest elevation angle for each of the passes, and schedules passes for acquisition based upon the operator's instructions. Computation and scheduling may be performed for as many as four different satellites. When enabled, the computer, at the appropriate times, automatically positions the antenna at the anticipated AOS position, and then steps along the predicted track until acquisition and autotrack are achieved. The program continues to run; if autotrack is lost for any reason, the system reverts to program track in an attempt to maintain data reception, and returns to autotrack if the tracking signal is re-acquired. After LOS the antenna is automatically returned to stow position and the next scheduled pass is announced. This subsystem was thoroughly tested after installation of the system at GSFC. The quality of program track data was compared to autotrack data. Program track met the design goals, providing the I^2RV data was current.

Tests performed with both the Landsat 4 and the Landsat 5 spacecraft have demonstrated Flight Segment to Ground Segment bit error rates of less than one part in 10^6 at antenna elevation angles as low as two degrees, exceeding system requirements.

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6.7 GROUND SEGMENT INTEGRATION AND VERIFICATION

The Landsat Ground Segment followed a standard methodology for integration and verification that differed very little from that proposed. It included the concept and schedule of Build tests, Stage tests, Facility tests, Ground Segment tests and Operational Readiness tests.

Although each facility (MMF, CSF, DRRTS, MIPS and TIPS) had common names for these series of tests, in practice each facility organized its test team and its methodology somewhat differently. Build tests were defined, planned and conducted by the Software Engineering organization as a means to demonstrate their progress. Stage and Facility tests were conducted by independent test teams. The Ground Segment Integrated tests and Operational Readiness tests were led by different managers. Quality Assurance checks were imposed at the Stage test level. Each test required a written plan, a written procedure and a written report. Tests beyond Builds were required to be approved by the Engineering Review Board before beginning and after completing. This step instilled a Ground Segment-wide discipline to the conduct of tests.

The next five sections discuss integration and verification activities within each facility, from Build testing through Facility tests. The last two sections address Ground Segment testing activities: (1) the Ground Segment Integrated Test (GSIT), and (2) the Operational Readiness Verification Tests (ORVTs).

As a result of the Landsat-D replan requirements, it became necessary to repeat tests that were already completed at the time of the rebaseline (mid-1980). Therefore, the summaries in this report give no date or results for some tests conducted before the rebaseline date.

6.7.1 MISSION MANAGEMENT FACILITY (MMF)

Progress of the development of the Mission Management Facility (MMF) was monitored and confirmed through a series of Build tests, Stage tests and a Facility test. Descriptions of these tests are summarized here.

6.7.1.1 MMF Build Tests

MMF Build tests were conducted for: (1) Data Base Administration Subsystem (DAS), (2) Ground Segment Management Subsystem (GMS), (3) Flight Segment Management Subsystem (FMS), and (4) Request Support Subsystem (RSS). A single Build test was conducted for the Interim TM Data System (ITDS). Dates and results of the MMF Build tests follow.

DATA BASE ADMINISTRATION SUBSYSTEM (DAS) BUILD TESTS

BUILD TEST	DATE	RESULTS
DAS Build 1	Jan. 80	Demonstrated that the data base load processor properly initialized the static records of the data base. (Pre-rebaseline)
DAS Build 1A	Dec. 80	Demonstrated that the data base load processor properly initialized the static records of the data base. (Repeat of DAS Build 1)
DAS Build 2	May 81	Demonstrated the capability to support DECNET interface protocol and VT78 terminal complex.
DAS Build 3	Jun. 81	Demonstrated common utility subroutines.
DAS Build 4	Dec. 81	Demonstrated five capabilities: (1) area record summary report, (2) area set summary report, (3) area chain chaser for production and archive product areas, (4) main image bit verifier dump of main image area records, and (5) main image bit verifier comparator of main image area records to dump files.

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GROUND SEGMENT MANAGEMENT SUBSYSTEM (GMS) BUILD TESTS

BUILD TEST	DATE	RESULTS
GMS Build 1	Jan. 80	Demonstrated the capability of the MMF to schedule HDT-R to HDT-A processing and to account for that processing. (Pre-rebaseline)
GMS Build 1A	Apr. 81	This build was necessary to demonstrate the design changes that were implemented to comply with the Landsat-D replan requirements. (Repeat of GMS Build 1)
GMS Build 2	Apr. 80	Demonstrated the capability of the MMF to schedule HDT-A to HDT-P processing. This build exercised automated cancellation and rework capabilities as well as the capability to account for successfully processed data. (Pre-rebaseline; TM only)
GMS Build 3	Jul. 80	Demonstrated the capability of the MMF to schedule final product generation from one or more P-tapes (HDT-Ps). This build exercised automated cancellation, startover and rework capabilities, as well as the capability to account for successfully processed data. (Pre-rebaseline)
GMS Build 3A	May 81	This build was necessary to demonstrate the design changes that were implemented to comply with the Landsat-D replan requirements. Demonstrated the capability

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		of the MMF to support final product film generation from HDT-A/CCT-P tapes. (Repeat of GMS Build 3)
GMS Build 4	Jul. 81	Demonstrated the capability to support final product CCT generation from HDT-A tapes.
GMS Build 5	Oct. 81	Demonstrated the capability to support Control Point Library build activities.
GMS Build 6	Aug. 81	Demonstrated the capability to support shipping of products, as well as DECNET transfer.
GMS Build 7	Nov. 81	Demonstrated the capability of the MMF to support product tracking, product assessment entry, inventory tape generation and operational tasks.
GMS Build 8	Sep. 81	Demonstrated the capability of the MMF to support product validation.
GMS Build 9	Jun. 81	Demonstrated the capability of the MMF to request regeneration of HDT-A tapes for specified scenes, to request regeneration of products (CCT and film) for specified scenes, and to request copy and/or uplink to EDC of HDT-A tapes.

FLIGHT SEGMENT MANAGEMENT SUBSYSTEM (FMS) BUILD TESTS

BUILD TEST	DATE	RESULTS
FMS Build 1	Jun. 80	Demonstrated that the candidate request generation process properly generates a file of candidate requests for use by the Flight Scheduling Subsystem (FSS), and that the candidate request feedback accounting process can properly account for the candidate requests using feedback generated by the FSS. (Pre-rebaseline)
FMS Build 1A	Mar. 81	Demonstrated that the candidate request generation process properly generates a file of candidate requests for use by the FSS, and that the candidate request feedback accounting process can properly account for the candidate requests using feedback generated by the FSS.
FMS Build 2	Jul. 81	Demonstrated four capabilities: (1) The input file transfer program successfully processes the transfer of DECNET files from CSF to MMF, including the detection of duplicate deletion or transfer requests. (2) The MSS telemetry ingest process successfully processes MSS telemetry directory and data files. (3) The telemetry/ephemeris packaging process successfully processes PCS Phase I output files. (4) The telemetry/ephemeris comparator process successfully examines the production area and the telemetry/ephemeris area of the MMF

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		data base to determine whether sufficient telemetry/ephemeris data exist to satisfy production requirements.
FMS Build 3	Dec. 81	Demonstrated the capability to merge MSS and TM candidate requests and to segregate MSS and TM candidate request status.

REQUEST SUPPORT SUBSYSTEM (RSS) BUILD TESTS

BUILD TEST	DATE	RESULTS
RSS Build 1		Pre-rebaseline.
RSS Build 1A	Nov. 81	Demonstrated the capability of the MMF to report on flight management activity, maintain and report on an inventory control system, and maintain and report on a problem defect tracking system.
RSS Build 2	Feb. 80	Demonstrated three capabilities: (1) browse capability to access main image records, (2) Interactive Query Language (IQL) capability to access and report on main image data records, and (3) common parameter maintenance capabilities to access and modify reeords in the common parameter area of the MMF data base.
RSS Build 2A	May 81	Demonstrated the capability of the MMF for interactive inquiry of available imagery and the generation of coverage catalogs for available imagery.

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RSS Build 3	Feb. 81	Demonstrated the capability of the MMF to enter standing orders for acquisition products and retrospective orders for products.
RSS Build 4	Dec. 81	Demonstrated the capability of the MMF to report on ground management activity, maintaining and extracting data from the spacecraft parameters World Reference System data base, and maintaining error code information in the MMF error-text data base.

INTERIM TM DATA SYSTEM (ITDS) BUILD TEST

BUILD TEST	DATE	RESULTS
ITDS Build 1	Apr. 82	Demonstrated the capability to archive raw TM data and to generate systematic correction data (SCD) tapes for the Scrounge system.

6.7.1.2 MMF Stage Tests

The MMF-M functions were integrated in five formal stage tests. Informal interfacility tests were performed on the CSF, MIPS and DRRTS to validate the interfaces.

There was only one MMF-T formal stage test. However, that stage test used "live" data collected by the ITDS, as opposed to the mostly simulated data used for MMF-M stage testing. There were also informal interfacility tests with MMF-M and TIPS, which validated these interfaces.

STAGE TEST	DATE	DEMONSTRATED
MMF Stage 1	May 81	Scenario 1 - Initialized the data base.
		Scenario 2 - Demonstrated software to delineate user data from the order data.
		Scenario 3 - Demonstrated the capability to enter order information.
		Scenario 4 - Demonstrated the use of interactive input to change status of a user and/or order.
		Scenario 5 - Demonstrated the ability to generate candidate requests.
		Scenario 6 - Demonstrated the generation of candidate requests for mission planning.
		Scenario 7 - Demonstrated the accounting for candidate requests.
MMF Stage 2	Jun. 81	Scenario 1 - Data base initialization.
		Scenario 2 - User and order information tape processing.
		Scenario 3 - Candidate request generation.
		Scenario 4 - Candidate request feedback accounting.

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		Scenario 5 - Stage two data base initialization.
		Scenario 6 - HDT-R directory entry.
		Scenario 7 - HDT-R directory inversion.
		Scenario 8 - Process request generation for archive generation.
		Scenario 9 - Archive generation process request feedback.
		Scenario 10 - Archive item close out.
		Scenario 11 - Archive generation rework.
MMF Stage 3	Sep. 81	Scenario 1 - Data base initialization for EROS Data Center (EDC) tape load.
		Scenario 2 - User and order information tape processing/DECNET protocol utilities.
		Scenario 3 - VT78 terminal complex support.
		Scenario 4 - Candidate request generation.
		Scenario 5 - Input file transfer/candidate request feedback.
		Scenario 6 - Tape backup for DECNET.
		Scenario 7 - Telemetry/ephemeris processing.

Scenario 8 - HDT-R directory entry.

Scenario 9 - HDT-R directory inversion.

Scenario 10 - Process request generation for archive generation.

Scenario 11 - Archive generation process request.

Scenario 12 - Archive item close out.

Scenario 13 - Route data base management.

Scenario 14 - Imagery browse.

Scenario 15 - User data entry.

Scenario 16 - User and order status modification.

Scenario 17 - Standby order information entry (manual mode).

Scenario 18 - Retrospective order entry.

Scenario 19 - Final product process request.

Scenario 20 - Final product film feedback.

Scenario 21 - Archive regeneration request entry.

		Scenario 22 - Quality assessment feedback.
		Scenario 23 - Photo lab process request generation.
		Scenario 24 - Photo lab film feedback.
		Scenario 25 - Product regeneration request entry.
		Scenario 26 - EDC retrospective HDT copy uplink.
		Scenario 27 - Wrap-up (prints file and logs off).
MMF Stage 4	Nov. 81	Scenario 1 - Initialization.
		Scenario 2 - User and order information processing/DECNET protocol utilities.
		Scenario 3 - Candidate request generation-scheduling activity.
		Scenario 4 - Operations log.
		Scenario 5 - Input file transfer/candidate request.
		Scenario 6 - Octal dump.
		Scenario 7 - Telemetry/ephemeris processing.

Scenario 8 - HDT-R directory entry.

Scenario 9 - HDT-R directory inversion.

Scenario 10 - Process request generation for archive generation.

Scenario 11 - Archive generation process request feedback.

Scenario 12 - Archive item close out.

Scenario 13 - Route data base management.

Scenario 14 - Imagery browse.

Scenario 15 - User data entry.

Scenario 16 - User and order status modify.

Scenario 17 - Standing order information entry (manual mode).

Scenario 18 - Retrospective order entry.

Scenario 19 - Final product process request generation rework.

Scenario 20 - Final product film feedback.

Scenario 21 - Archive regeneration request entry.

Scenario 22 - Quality assessment feedback.

Scenario 23 - Photo lab process request generation.

Scenario 24 - Photo lab film feedback.

Scenario 25 - Product regeneration request entry.

Scenario 26 - EDC retrospective HDT copy uplink.

Scenario 27 - Final product tape feedback (manual).

Scenario 28 - MMFCC CCT process request generation.

Scenario 29 - MMFCC CCT copy feedback.

Scenario 30 - DRRTS process request generation.

Scenario 31 - DRRTS uplink and copy feedback.

Scenario 32 - Wrap-up.

MMF Stage 5	Jan. 82	Management reports and tracking.
MMF Stage 6	Nov. 82	Four objectives: (1) Created an integrated test environment from CMO controlled library. (2) End-to-end integration of MMF-T.

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(3) Established a baseline for interface testing.

(4) Use "live" ITDS data for testing.

6.7.1.3 MMF Facility Tests

The MMF Facility Test was conducted in February 1982 to verify MMF capabilities.

6.7.2 CONTROL AND SIMULATION FACILITY (CSF)

The Control and Simulation Facility (CSF) followed the master scheme for staged integration and verification, but added some unique tests not found in the other facilities. In early July 1981 (Program Directive No. 215), it was directed by the Program Office that a new series of tests be conducted. These major item verification tests (MIVTs) were to verify all requirements at the subsystem level. It was originally intended to do this verification in the stage tests, but early results from stage testing showed this not to be feasible due to schedule slips, the amount of formal control required and the staged subsystem implementation scheme. As a result, stage test objectives were concentrated on testing functionality of the incremental subsystem builds and MIVTs concentrated on requirements verification for completed subsystems.

The CSF was involved in many external interfaces that required additional testing. These included the Flight Segment/Ground Segment Compatibility Tests, several interface tests, and an FOS Confidence Test. These tests will be discussed further under Facility testing.

6.7.2.1 CSF Build Tests

The builds were defined for DDR in early 1980, and several were completed, tested and verified prior to the rebaseline in late 1980. The post-rebaseline builds were defined to include the entire new baseline. A brief description of each build and the test date are listed below by subsystem:

BUILD	TEST DATE	DESCRIPTION
TSIM-4	Dec. 80	Simulation support, real-time simulation.
TSIM-4A	Feb. 81	Rerun of TSIM-4 with upgraded VMS (version 2.1).
TSIM-5	May 81	Integration of Nascom and FOS into simulations.
TSIM-5A	Sep. 81	GPS modeling.
FOS-1	Jan. 81	Nascom, COIL.
FOS-2	Mar. 81	Data base.
FOS-3	May 81	Telemetry processing.
FOS-4	Jun. 81	Operator control and display.
FOS-5	Aug. 81	Command.
FOS-6	Nov. 81	Communications control.
FSS-2	Mar. 81	Uplink data generation.
FSS-3	May 81	Scheduling support.
FSS-4	Aug. 81	Acquisition analysis.
FSS-5	Jul. 81	Mission scheduling.
FSS-6	Oct. 81	Mission scheduling.
FSS-7	Dec. 82	D-Prime, TDRSS.

PES-1	Nov. 81	Telemetry display.
PES-2	Jan. 82	Spacecraft analysis.
NCC-1	Nov. 81	Message routing.
NCC-2	Aug. 82	Real-time message routing.
NCC-3	Sep. 82	MPT integration.

6.7.2.2 CSF Stage Tests

Each stage test was comprised of several builds from various subsystems, which together represented a major function of the CSF. An incremental baseline of control center functionality was thus built and exercised through the stage tests. The test date and a brief description of each stage follows:

BUILD	TEST DATE	DESCRIPTION
2	Mar. 81	Initial stage baseline procedures. TSIM telemetry generation. FOS telemetry processing. FSW baseline scenarios.
3	May 81	Data base and MIT files. NIF/SU interface. COIL, OBC, uplink data tests. FOS performance testing.
4	Jul. 81	Process TSIM telemetry and dump data. Scheduling support software. Performance measurement. COIL testing continued.

5	Sep. 81	COIL stress testing. Real-time processing performance measurement. FSS reverification. PCD, STR data processing.
6	Feb. 82	Mission scheduling. Acquisition accounting. FOS/TSIM continuous orbital operations. Performance measurement.
7	Feb. 82	Full CSF capabilities.
8	Sep. 82	NCC message generation and processing. Real-time NCC operations.
9	Dec. 82	D-prime.

6.7.2.3 CSF Major Item Verification Tests

The major item verification tests (MIVTs) concentrated on subsystem requirements for verification instead of system functions. Other areas that were monitored during the MIVTs included: software as-built documentation, unit development folders, outstanding discrepancy reports (from unit, build and stage testing), and CMO baseline of the MIVT test items. The MIVTs, test dates and contents were:

MIVT	TEST DATE	DESCRIPTION
1	Sep. 81	Nascom I/O scheduling support.
2	Nov. 81	Operator control and display. Telemetry processing.
2A	Nov. 81	Repeat of MIVT 2 after problem correction.

3	Jan. 82	Test and simulation subsystem.
4	Mar. 82	Flight scheduling. Network control center.
5	Feb. 82	Performance evaluation. Command. Communication control. Network control. Support services.

6.7.2.4 CSF Facility Tests

There were several facility-level tests conducted in the CSF prior to the launch of Landsat-D. They are listed below:

Facility Test	Mar. 82
CSF Interfaces:	
CSF/TGS	Aug. 81
TGS/DRRTS	Dec. 81
MMF/CSF	Nov. 81
CSF/DRRTS	Feb. 82
Van Compatibility Tests	Jan. 82 and May 82
Network Data Flows	Apr.-Jun. 82
Network Launch Simulations	Jun.-Jul. 82
Launch/Early Orbit	Jun. 82
24-hour Scheduling Test	Jun. 82
CSF All Hands Launch Simulation	Jul. 82

The majority of these tests were related to launch readiness evaluations. The rest were verifications of interfaces within the Ground Segment. All of the tests were directed by I&T or Systems Engineering personnel and performed by the operations crew. The tests served both as verification and training exercises. All of the tests were concluded successfully; problems encountered were documented on PDRs and resolved before the next test. The Van

Compatibility Test was repeated four months later for several reasons: the spacecraft was available for a week prior to shipment to the West Coast, the CSF had been through several facility-level tests during that four-mounth period, the data base and procedures had matured considerably and were basically flight-ready. The second van test was very successful and bolstered our confidence.

In parallel with this series of Facility tests in the CSF, the rest of the Ground Segment was going through Facility, Ground Segment and Operational Readiness testing. The CSF participation in these tests was kept to a minimum to allow the control center and crew to concentrate on launch readiness. Test data, processing of incoming interface data and points of contact were provided primarily by the I&T team members not directly involved in launch readiness. These tests are further described later in this report.

Facility tests conducted prior to the launch of Landsat-D Prime were:

Facility Test	Jan. 84
FOS Confidence Test	Nov. 83
Van Compatibility Test	Jan. 84
Network Data Flows	Jan.-Feb. 84
Network Launch Simulations	Feb. 84
Launch/Early Orbit	Feb. 84
CSF All-hands Launch Simulation	Feb. 84

All of the tests were directed by GE Systems Engineering and performed by NOAA contractors, except for the Facility test, which was totally performed by the NOAA contractor.

6.7.3 DATA RECEIVE, RECORD, TRANSMIT SYSTEM (DRRTS)

Progress of the development of the Data Receive, Record, Transmit System (DRRTS) was monitored and confirmed through a series of Build tests, Stage tests, and a Facility test. Descriptions of these tests are summarized here.

6.7.3.1 DRRTS Build Tests

The DRRTS had three software Build tests defined. These tests were:

BUILD TEST	TEST DATE	RESULTS
Build DRRTS 1	Sep. 81	Demonstrated the ability to control the high density digital tape records.
Build DRRTS 2	Nov. 81	Demonstrated the full data receive, record and transmit capabilities, including directory generation for MSS data.
Build DRRTS 3	May 82	Demonstrated the full data receive, record and transmit capabilities including directory generation for TM data.

The first and second DRRTS Build tests were the foundation for the first Stage test and then an MSS Facility test, led by the DRRTS System Engineer, in January 1981. The third Build test was conducted along with the second Stage test (a demonstration of TM capabilities).

The DRRTS testing was highly successful due to the following factors: (1) well-planned tests, (2) availability of test data from simulators or test tapes, (3) prompt elimination of hardware and software defects, (4) special attention paid to hardware and software configuration control, and (5) close cooperation between the testers, the hardware maintenance staff and software engineering.

6.7.3.2 DRRTS Stage Tests

There were two DRRTS Stage tests. Stage test one was conducted in January 1981, and Stage test two, a demonstration of TM capabilities, was conducted in May 1982.

6.7.3.3 DRRTS Facility Test

The DRRTS FAcility test was included in the Ground Segment Integration Test in March and April 1982.

6.7.4 MSS IMAGE PROCESSING SYSTEM (MIPS)

Development of the MSS Image Processing System (MIPS) was monitored and confirmed through Build tests, Stage tests, and a Facility test. A summary of these tests is contained here.

6.7.4.1 MIPS Build Tests

The MSS Image Processing System (MIPS) Build tests were conducted for: (1) MSS Archive Generation (MAG), (2) Performance Evaluation Product Generation (PEPG) - A, (3) Performance Evaluation Product Generation (PEPG) - P, (4) Control Point Library Build, (5) Payload Correction Subsystem, and (6) Manual Cloud Cover Assessment (MCCA).

MSS ARCHIVE GENERATION (MAG)

Four Build tests were related to MSS Archive Generation (MAG):

BUILD TEST	TEST DATE	RESULTS
Build MAG 1	Jul. 81	Demonstrated the completeness and accuracy of calculation phase algorithms and showed what an operator experiences during the production of an MSS HDT-A tape.
Build MAG 2	Aug. 81	Demonstrated the equivalence of AP-180V calculation phase software to VAX software demonstrated in Build 1 and demonstrated the correctness of output phase software by producing an output computer compatible tape.

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Build MAG 3	Nov. 81	Demonstrated the entire MAG package in a standalone fashion including ingest, calculation and output processing.
Build MAG 4	Nov. 81	Demonstrated the interface of the MAG-3 build with the manual cloud cover assessment and quality assurance film generation to show MSS archive generation processing in a realistic environment.
		Builds MAG 3 and 4 were combined into one test.

PERFORMANCE EVALUATION PRODUCT GENERATION (PEPG) - A

Two Build tests were conducted in relation to the Performance Evaluation Product Generation (PEPG) - A:

BUILD TEST	DATE	RESULTS
Build PEPG 1	Jul. 81	Provided a minimal operational evaluation product generation capability that served as the foundation for subsequent Build tests.
Build PEPG 2	Sep. 81	Demonstrated full capability to process partially corrected scene data including activation and control by the CCP.

PERFORMANCE EVALUATION PRODUCT GENERATION (PEPG) - P

BUILD TEST	DATE	RESULTS
Build PEPG 3	Jan. 82	Demonstrated the fully operational PEPG system.

CONTROL POINT LIBRARY BUILD (CPLB)

There were three Build tests associated with the Control Point Library Build:

BUILD TEST	DATE	RESULTS
Build CPLB 1	Sep. 81	Demonstrated the ability to identify latitude and longitude of candidate control points and the ability to analyze control point neighborhoods that fail to correlate.
Build CPLB 2	Jan. 82	Demonstrated the ability to correlate control points using Comtal and Zoom transfer scope, and extract and geometrically correct a candidate control point neighborhood from A-tape data.
Build CPLB 3	Jan. 82	Demonstrated the ability of the control point library build software to interface with the MIPS control and communication package. Builds CPLB 2 and 3 were combined into one Build test.

PAYLOAD CORRECTION SUBSYSTEM (PCS)

BUILD TEST	DATE	RESULTS
Build PCS 1	Oct. 81	Demonstrated the ability to generate systematic correction data from pre-smoothed attitude, ephemeris and telemetry data.

Build PCS 2	Jan. 82	Demonstrated the ability to generate systematic correction data after processing spacecraft attitude, ephemeris and telemetry data.

MANUAL CLOUD COVER ASSESSMENT (MCCA)

BUILD TEST	DATE	RESULTS
Build MCCA 1	May 81	Demonstrated: (1) display of menu, (2) acquisition of operator commands, (3) interface with control and communication package, (4) interface with the Logger utility, (5) generation of a summary display of scenes in the current work order, (6) application of radiometric corrections to subsampled image data, (7) display of radiometrically corrected image data and annotation on Comtal display, (8) acquisition from the operator of cloud cover scores for each quadrant of each scene in a work order, and (9) generation of a processing summary report.

6.7.4.2 MIPS Stage Tests

MIPS testing included five Stage tests.

STAGE TEST	DATE	DEMONSTRATED
MIPS Stage 1	Nov. 81	Scenario 1 - Initialization (cold startup of a MIPS string).

		Scenario 2 - Generation of CCT-AM from HDT-AM (production mode).
		Scenario 3 - Generation of summaries, dumps, performance evaluation (PE) reports and Comtal displays.
		Scenario 4 - Comtal scene displays.
		Scenario 5 - Interactive summaries, dumps and PE report generation.
		Scenario 6 - Ingest of CCT-AM.
		Scenario 7 - Generation of CCT-AM from HDT-AM (engineering mode).
		Scenario 8 - Ingest of HDT-AM.
		Scenario 9 - Test pattern generation.
		Scenario 10 - Termination.
MIPS Stage 2	Jan. 82	Scenario 1 - String startup test.
		Scenario 2 - Line test.
		Scenario 3 - Control and communication test.
		Scenario 4 - Timing, concurrent operation and disk capacity test.
		Scenario 5 - Radiometric correction test.

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		Scenario 6 - Control point correlation and SCDG/GCDG test.
MIPS Stage 3	Feb. 82	Scenario 1 - Scene selection and candidate GCP selection.
		Scenario 2 - Candidate GCP digitization.
		Scenario 3 - Control point generation.
		Scenario 4 - Relative control point generation.
		Scenario 5 - Control point display.
		Scenario 6 - Landsat 2/3 GCP conversion and termination.
MIPS Stage 4	Jan. 82	Scenario 1 - Initialization.
		Scenario 2 - Normal payload correction system (PCS) processing.
		Scenario 3 - Anomalous data processing.
		Scenario 4 - Error recovery.
		Scenario 5 - Parallel operation.
MIPS Stage 5	Apr. 82	Scenario 1 - Initialization.
		Scenario 2 - Generation of CCT-PM from HDT-AM.

Scenario 3 - Ingest of CCT-PM.

Scenario 4 - Comtal scene display.

Scenario 5 - Interactive summaries, dumps, and performance evaluation (PE) reports.

Scenario 6 - Ingest of CCT-AM.

Scenario 7 - Test pattern generation.

Scenario 8 - Termination.

6.7.4.3 MIPS Facility Test

The MIPS Facility Test was conducted along with the Ground Segment Integration Test.

6.7.5 TM IMAGE PROCESSING SYSTEM (TIPS)

Development of the TM Image Processing System (TIPS) was monitored and confirmed through Build tests, Stage tests, and a Facility test. A summary of these tests is contained here.

6.7.5.1 TIPS Build Tests

TIPS Build tests were conducted for: (1) TM archive generation (TAG), (2) TM data quality assessment (TDQ), (3) TM initial product generation (TIG), (4) TM final product generation (TFG), (5) TM control point library build (TCL), (6) TM payload correction system (TPC), and (7) quality assurance film build (TQF).

TIPS ARCHIVE GENERATION (TAG) BUILD TESTS

BUILD TEST	DATE	RESULTS
TAG Build 1	Oct. 82	Demonstrated the Pass 2 archive generation capability with image data output to disk using the Parallel to Serial Data Output Device (PSDO) simulator.

TAG Build 2	Oct. 82	Demonstrated correction data processing capability, including radiometric correction, correlation and auxiliary data generation.
TAG Build 3	Mar. 83	Demonstrated full TM HDT-AT generation capability, including TAG Build 1 and TAG Build 2, Pass 1 archive generation and manual cloud cover assessment.

TIPS DATA QUALITY ASSESSMENT (TDQ) BUILD TESTS

BUILD TEST	DATE	RESULTS
TDQ Build 1	Mar. 83	Demonstrated a minimal operational system.
TDQ Build 2	Apr. 83	Demonstrated full high density digital tape capabilities.
TDQ Build 3	Apr. 83	Demonstrated full data quality assessment capabilities.

TIPS INITIAL PRODUCT GENERATION (TIG) BUILD TESTS

BUILD TEST	DATE	RESULTS
TIG Build 1	Oct. 82	Demonstrated the geometric correction capability.
TIG Build 2	Mar. 83	Demonstrated full initial product generation capability, generating high density digital product (HDT-P) tapes from high density digital archival (HDT-A) tapes.

TIPS FINAL PRODUCT GENERATION (TFG) BUILD TEST

BUILD TEST	DATE	RESULTS
TFG Build 1	Mar. 83	Demonstrated the full capabilities of the final product generation package.

TIPS CONTROL POINT LIBRARY (TCL) BUILD TEST

BUILD TEST	DATE	RESULTS
TCL Build 1	Apr. 83	Demonstrated the full capabilities of the control point library build package.

TIPS PAYLOAD CORRECTION SYSTEM (TPC) BUILD TEST

BUILD TEST	DATE	RESULTS
TPC Build 1	Oct. 82	Demonstrated the full capabilities of the TIPS payload correction system package.

TIPS QUALITY ASSURANCE FILM (TQF) BUILD TEST

BUILD TEST	DATE	RESULTS
TQF Build 1	Apr. 83	Demonstrated the full capabilities of the quality assurance film generation package.

6.7.5.2 TIPS Stage Tests

There were four Stage tests conducted to verify that requirements of the TIPS Specification, GES 10081, were met. Stage tests were scheduled to be conducted in three phases: (1) test data generation, (2) test plan and procedure generation, and (3) actual testing, analysis and presentation of results. A listing of these four tests follows.

STAGE TEST	DATE	RESULTS
TIPS Stage 1	Oct. 82	Demonstrated operation of the payload correction system (PCS) to process TM payload correction data (PCD-T) and to produce systematic correction data.
TIPS Stage 2	Mar. 83	Demonstrated the generation of archival high density digital tape (HDT-A) by processing TM raw video data contained on an HDT-R tape to partially corrected data on both an HDT-A tape and 70 mm film.
TIPS Stage 3	Mar. 83	Demonstrated the generation of initial product high density digital tape (HDT-P) by processing TM archival data contained on an HDT-A tape to geometrically corrected data on an HDT-P tape.
TIPS Stage 4	Apr. 83	Demonstrated the capability to generate CCTs by scene quadrants from HDT-A tapes and HDT-P tapes and generating 241 mm film from HDT-P tape data. This test also demonstrated the creation of new control points from recently acquired Landsat-D imagery and operation of the control point library build process.

6.7.5.3 TIPS Facility Test

The TIPS was released to the Ground Segment as one facility. The Facility test was completed in June 1983. The TIPS Facility test verified requirements

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that had been deferred from or failed in the four stage tests. Requirements from the Ground Segment Specification, GES 10045, were verified.

6.7.6 GROUND SEGMENT INTEGRATION TEST (GSIT)

The Ground Segment Integration Tests (GSIT) were conducted during March and April 1982. The primary objectives of the GSIT were: (1) to demonstrate the Ground Segment as an integrated functional entity and to establish the GSIT baseline for future enhancements, and (2) verify Ground Segment requirements. Secondary objectives were: (1) to demonstrate the Ground Segment using operational scenarios in preparation for the operational readiness period, and (2) to maximize early M&O involvement at all levels to facilitate transition to the ORVP.

A comprehensive series of integrated Ground Segment activities was structured to simulate a multiple-day operational scenario. Subjects included were: (1) user request processing, (2) Flight Segment planning and scheduling, (3) orbital operations and data acquisition, (4) image data acquisition and transmission, (5) product generation, quality assurance, and distribution, (6) mission data management, (7) inventory control and problem defect report (PDR) tracking, and (8) management control and reporting.

6.7.7 OPERATIONAL READINESS VERIFICATION TEST (ORVT)

The ORVT extended from April 1982 to July 1982. Key objectives for the ORVT were: (1) verify operational readiness of maintenance and operations, and (2) complete development, integration and validation of the Landsat-D launch baseline. The ORVT was conducted in three phases.

The objective of Phase One was to demonstrate Ground Segment Release 2.0. Phase One was, in effect, a re-run of the GSIT with several modifications and/or additions. Telemetry was generated by TSIM. Operational CSF software generated all interface data items from CSF to MMF. The test exercised the interfaces between CSF and MMF in a semi-operational mode.

The objectives of the ORVT Phase Two test were to demonstrate an integrated Ground Segment with end-to-end data flows and to exercise internal operational interfaces. Operational requirements of TSIM were verified. Operational readiness of standard operating procedures and of M&O personnel was demonstrated. Phase Two consisted of two parts. The first part included activities associated with launch and early orbit activation tasks. The second part consisted of Ground Segment activities that exercised the OCC and DMS in an integrated end-to-end operational mode. The Flight Segment was represented by the TSIM.

The objective of Phase Three was to demonstrate the operational readiness of the Ground Segment in a real-time mode of operation. MMF and CSF performed their scheduling functions. All external interfaces were tested. Phase Three was a full-up Ground Segment test with a duration of five days.

6.8 LANDSAT-D/D PRIME DESIGN ENHANCEMENTS

6.8.1 MMF DESIGN ENHANCEMENTS

As with any system that is developed over a period of years, the MMF was modified by design enhancements. Those enhancements that were implemented prior to the program rebaseline of mid-1980 are discussed in this paragraph; the remainder are discussed in paragraphs 6.8.1.1 and 6.8.1.2. It must be noted that the design enhancements to the MMF-M software were also carried over to the MMF-T software design.

The major hardware enhancement in the MMF was a CPU/main memory upgrade to the DEC System 10. The model 1091 central processor was upgraded to become equivalent to that of a DEC System 20 Model 2050 and the main memory size was doubled. This paved the way for the DEC System 20 being the model line for the two MMF systems in the Ground Segment.

6.8.1.1 MMF-M Design Enhancements

The initially conceived control mechanism for the MMF-M software executables was that of hard-coded job control streams that invoked a series of programs in one "transaction." This concept was replaced by a new control processor, the Menu, which allowed for "transaction" processing as well as for the execution of each individual program. The Menu was developed so that it would be very user friendly, taking the production control operator through the logical data flow paths by way of layered process selection screens. The Menu performed standard functions for each program (e.g., printing the summary reports) as well as allowing for command files to be tailored to the needs of the individual programs. The Menu also provided for the implementation of "run time switches" which replaced the use of data base parameters as a way of having the operator control certain run-time aspects of the program. This feature allowed, for example, the production control operator to run a given process in a selective mode (e.g., to expedite high priority data sets), or in a batch production mode. This particular feature was implemented because there was an overall design upgrade to the MMF-M software that required all processes to have the operator selection option. This option proved invaluable during the initial operations phase, when problem data sets routinely encountered were bypassed via operator selection.

Another major design enhancement to the MMF-M was in the area of the production control software. Scenes in the various steps of processing (archive generation, product dissemination, PEPG) were to be restatused after each processing step by the MMF-M application software. The status transitions were originally hard-coded in the application software. These status transitions were abstracted out of the software and embedded as data elements in the MMF-M processing route step data base area. This abstraction significantly simplified the product processing approach and was directly transferable to the MMF-T system, which dealt in a more complex product mix.

Numerous software development/maintenance tools were developed or acquired during the MMF-M development era. Some of these tools became a part of the operational system in addition to benefiting the software development. The full screen file browse tool and full screen editor became tools for operational verification of process completion and for problem data set investigation/correction. An MMF-M cross-reference data base was developed to provide automated data base data dictionary generation, software module/data base element correlation, and software lines of code counts.

6.8.1.2 MMF-T Design Enhancements

In addition to the MMF-M design enhancements that were incorporated into the MMF-T design, there were numerous design modifications made to the MMF-T alone.

In the hardware area, there were two major design enhancements. The mid-1980 NASA D-100B specification required only 12 TM scenes per day be processed. In light of that requirement, GE selected a DEC System 2040 for the MMF-T host computer. As indications of the final system requirement of 100 TM scenes per day resurfaced, the plans for the DEC System 2040 were rapidly changed, and the order for a DEC 2040 was changed to a DEC 2060. This "on-paper" enhancement was advertised to increase the processing power of the MMF-T by a factor of three.

Through the development phase of the MMF-T system, the mass storage system was augmented to a total of 8 Model RP06 disk units, one of which was the switchable disk, used for MMF-M/MMF-T data transfer. An additional disk controller was added in order to distribute the mass storage demand, resulting in a balanced system of four disk units on each controller.

The original MMF-T configuration had two Model TU77 tape drives, capable of recording at 800 or 1600 bpi. When the TM archiving subsystem began recording PCD and video tape directory data for 60-90 scenes per day, the need for higher density CCT tape drives became evident. Two model TU78 tape drives (1600 or 6250 bpi recording density) were added to the MMF-T configuration.

The final hardware enhancement made to the MMF-T was to the DEC 2060 main memory. The 512K 36-bit words of MOS memory was removed and replaced with 1024K 36-bit words of a newer model MOS memory. This main memory swap resulted in a noticeable performance improvement during periods of moderate to high system load.

There were several design enhancements made to the MMF-T software system during the development period. One of the most complex software design enhancements was in the area of TIPS and PCS parameters maintenance. The parameters maintenance design allowed for temporal parameter changes, but not for absolute parameter changes. This meant that new parameter values could be installed so that processing of future scenes would use the new values, but processing of older scenes would not. This design was enhanced to allow for "retroactive" dates of applicability. The design enhancement also allowed for the retention of the previous parameter files, which would be marked as "inactive," for historical purposes.

Since the TIPS and PCS parameters maintenance was being performed in a production support environment that was separated from the production data base, a "population" step was performed with each parameter installation. This step involved adding index records in the production data base for the newly-generated parameter files and copying the new parameter files into the production account. This manual process was automated with the final parameters maintenance design enhancement, known as the automated parameter population module.

Two applications programs were added to the MMF-T data base maintenance area as design enhancements. The directory area maintenance utility, DBFILE, allowed operations personnel to manipulate the current index/delete index lists in the data base, which proved to be a very powerful and flexible capability. The production area status modification utility, DBSTAT, allowed operations personnel to restatus for reprocessing scenes failed by PCS, after corrective action had been taken. This utility also allowed for a more potent capability to alter the status of any scene in the production area. This capability, which was reserved for use by the data base administrator, was utilized in a housekeeping fashion periodically; e.g., to cancel bad data sets.

One of the most beneficial design enhancements to the MMF-T was in the area of concurrent data base operations. Although no two data base updating programs were allowed to be run concurrently, a data base read-only program could theoretically run concurrently with a data base updating program. The drawback of the concurrent operation was that the data values being examined by the read-only program could, at the same time, be modified by the updating program. In order to avoid these "window" where the data could change without the examiner's knowing it, locking mechanisms were installed in all COBOL management report programs. These were the same standard locking mechanisms used in data base-updating programs to avoid data modification "collisions." The performance benefits of concurrent operations so far outweighed the consequences of a "window" data modification that the locking mechanisms were removed from all COBOL management report programs. Since at least three of the reports were run daily, this design enhancement paid for itself in a short period of time. Another concurrency benefit was achieved when the data base examine capability was "cloned" from the generalized data base update program. This new program allowed the operations staff to perform data base inquiries and to track down problems without interrupting the production flow.

6.8.2 CSF

There were few design enhancements required for Landsat-D Prime operations in the CSF. In the area of hardware, a new Nascom switch was installed that replaced both the matrix switch and the original Nascom switch. It considerably simplified the switching of lines and removed several potential sources of operator and hardware error. Based on results of performance analysis studies for dual spacecraft operations, an additional megabyte of memory was added to each of the three CSF VAXes. A dedicated disk drive was added to each VAX. These drives were pulled from a MIPS string; the string was then dedicated to supporting FSS activities for the two spacecraft.

In the area of software, there were no enhancements made to PES or TSIM. The FOS software was already compatible with Landsat-D Prime but was modified for performance enhancement. Significant gains were achieved in memory usage and speed. The NCC and FSS software required substantial data base parameter updates; some enhancements for performance were also made. The NOAA contractor chose to modify file and data names to reflect spacecraft IDs and prevent corruption of one set of spacecraft data by the other. The entire system architecture (directories, accounts, etc.) was modified to separate the inputs and outputs of each spacecraft and embed protective measures to prevent corruption of data.

6.8.3 DRRTS

For Landsat-D Prime, the TM demultiplexers in DRRTS were required to be upgraded to detect the Landsat 5 spacecraft identification in the data stream. Software then had to be upgraded to print messages an write into files the correct spacecraft identification. Additionally, the TM simulator was upgraded to output Landsat 4 or Landsat 5 spacecraft identification.

The directory generation and MMF service routine software modules were significantly optimized to enhance the overall DRRTS throughput. Additionally, TM MSCD formatted dump program was developed to aid in diagnosing TM MSCD related programs.

6.8.4 MIPS

No hardware changes were required for MIPS to accept Landsat 5 data. The system architecture was structured to accept Landsat 5 files from the MMF-M for process requests and parameter files, but system messages and reports had to be upgraded to print or write in files the appropriate spacecraft identification.

One of the MIPS strings was restructured to support the Control and Simulation Facility (CSF) changes for Landsat-D Prime. Three disk drives were removed from MIPS string #1 and reinstalled in CSF.

Additional unconfigured utility and diagnostic software was developed to support the MIPS maintenance and operations. Two significant software items were: 1) MIPS manager software, and 2) super diagnostic software. The MIPS manager software is a tool for functions such as creating and populating MIPS directories, editing and dumping parameter files, work order sets and internal files, etc. The super diagnostic software provides an easy way to have canned sets of diagnostics run using device drivers and exercisers.

The radiometric correction algorithm was enhanced to implement a limitation scheme for the scene content correction algorithm to restrict the divergence of corrections on flat radiance scenes (e.g., clouds or water, etc.).

6.8.5 TIPS

The TIPS underwent many design enhancements during the period from program rebaseline until system turnover. Enhancements were made in the areas of software, hardware, system optimizations, algorithms and tools.

6.8.5.1 Software

Several software enhancements were made in order to increase the operability of the TIPS. First, units of work transferred from the MMF-T were placed into a hold queue rather than automatically scheduled for processing. This change increased the operator's control over the system. Second, in order to reduce the frequency with which the operator was required to purge the disks, disk space optimization enhancements were implemented. These included deletion of the ASCII MMF-T process request files upon successful incorporation and the sharing of non-image data files between various non-concurrent processes.

6.8.5.2 Hardware

Six major hardware design enhancements were made in the TIPS system. First, an additional pair of RP06 disks were added to each TIPS string for use in control point library build. This addition reduced the contention for the main image disk pairs. Second, an additional megabyte of memory was added to each TIPS string. This change reduced program paging during concurrent processing, such as geometric correction and control point library build. Third, the downlink synchronization module was modified to detect the spacecraft identification in the time source digits of the thematic mapper data stream. The fourth major hardware design enhancement was the modification of the TM simulator to output Landsat 4 or Landsat 5 spacecraft identification.

The integrity and reliability of the FFP interfaces were greatly enhanced by: 1) replacing unnecessary cabling by hard wiring, 2) redoing the chassis ground, and 3) repositioning the VAX interface to reduce cable length (from 10 feet to 0.5 feet).

Finally, the maintainability and operability of the laser beam recorder was enhanced by: 1) addition of a photo diode and digital readout to monitor laser intensity, 2) addition of an external switch to allow continuous generation of gray scale control stock, and 3) interface electrical changes to ease several potential race conditions.

6.8.5.3 Systems Optimizations

System optimization design enhancements were made in three areas: 70 mm film generation, radiometric correction and CCT generation.

6.8.5.3.1 70 mm Film Generation

The GSFC D100C specification states: "At least the following shall be recorded on 70 mm film: two TM bands selectable from any of the seven available." The real use for 70 mm film is as a quality assessment tool and, as such, only one band is required. The TIPS was built with the capability of generating either one or two bands of 70 mm film. Operationally, the single band option is used in order to minimize film used, disk space used and film generation time.

6.8.5.3.2 Radiometric Correction

The RC segment size was first increased from 360 to 720 scans and the number of subsegments reduced from three to one. The latter resulted in no subsegment smoothing. Later, as a result of a TM radiometric correction R&D study, the number of subsegments was increased to six.

The scene content correction (SCC) is set up as an iterative process. Originally, four iterations were being performed. These were found to be excessive as convergence is usually achieved after one pass. A TM radiometric correction R&D task checked this out in detail. It was determined that the relative radiometric correction performance requirements were being met after at most two passes of SCC. Further passes did not improve results. The number of SCC passes were then reduced to two for both Landsat 4 and 5. There was also a substantial time savings by this reduction.

6.8.5.3.3 CCT Generation

The GSFC D100-C specification requires that the spacecraft maintain "A precise swath pattern which will repeat each 16-day cycle within $\pm$ 5 km maximum." The CCT format divided the scene into four quadrants centered at the WRS scene center. The image record length was chosen to allow up to a $\pm$ 10 km variation about the WRS scene center, thus generously satisfying the D100-C requirement. However, during early post-launch Landsat 5 activation, when the spacecraft was a much as 86 km off the WRS, it was impossible to generate CCTs of the imagery. The CCT generation software was modified to frame the imagery as though the offset were zero, if the cross-track variation was excessively large. Such CCTs would be labeled 'NOT ON WRS' since they violated the EDC ICD.

6.8.5.4 Algorithms

Most of the algorithmic enhancements in the TIPS were in the radiometric correction area. The first was to the regression algorithm that computes the gains and biases. The previous design used a weighted linear regression scheme. The weights were proportional to the number of scans that formed a cal state and inversely proportional to the detector noise. This was found to be incorrect. Several schemes were tried, but in the end an unweighted linear regression design was selected. This was best able to reproduce the pre-launch gains and biases, when appropriate pre-launch data was processed.

There are eight cal lamp states, all of which can be used in the regression step to compute the gains and biases. It was noticed that for the brightest lamp state (state 111, when all three lamps are on), cal values for some bands will saturate. The saturation effect would cause an undesirable effect in the regression. It was decided to eliminate states 111 and 000 (when all lamps are off) from the regression.

After the gains and biases are computed using linear regression, they have to be checked for validity. Originally, a scheme based on statistical tests was used. This, however, only checked the error in the linear fit, but not that the fit was reasonable. It was also a CPU intensive process. The new algorithm checks that the fit is good as well as reasonable. It does this at a substantial savings of time, as only a few additional calculations have to be made over the computation of the gain and bias.

The histogram adjustment process on certain kinds of data tends to diverge instead of converging. A limitation scheme was developed that would restrict the process from diverging. It essentially imposed limits on quantum levels over which the histogram means and standard deviations are computed. This reduces the possibility of striping.

For processing purposes the radiometric correction software breaks up the interval into segments. This invariably leaves a partial segment at the end of the interval. Previously, the partial segment was ignored for the computation of the RLUTs. The software changed to combine the partial segment with the previous full segment, thus allowing for more reliable gain and bias computation for this segment.

Shading factors are used to compute the effective radiance for each detector, for each lamp state. The original algorithm was developed under the assumption that shading factors wee independent of the lamp state. Thus only 100 (one for each detector) were necessary. Subsequent analysis indicated that this was not so and that 800 shading factors were required. The software and parameter files were therefore modified to incorporate this change.

The only significant non-radiometric correction enhancement control point neighborhood (CPN) was in the correlation area. The base dimensions of the CPN (128 x 256 pixels) are derived from spacecraft parameter and sensor alignment uncertainties. Since these uncertainties are reduced for a given CP by knowledge of the CP dislocations for the same general regions, it is possible to reduce the search dimensions whenever a statistically good local mean is available. The aim is to reduce both dimensions by a factor of two. This reduces the correlation time from about four seconds to about one second. Further reduction is not considered to be "cost-effective."

6.8.5.5 <u>Tools</u>

Three main categories of tools were provided. First, tools were developed that enhanced the capability to assess the quality of the TIPS products. Second, tools were developed to aid in the evaluation of the TM instrument, and the radiometric correction of the Ground Segment. Finally, tools were developed for engineering use in debugging problems and assessing performance. The development and implementation of comprehensive hardware diagnostics greatly facilitated troubleshooting.

6.8.5.5.1 Quality Assessment

CCT Profile was developed to provide a quick quality assessment (but not including video) of CCTs generated by the TIPS. CCT Profile:

a. Gives a profile of the files and records on the CCT-AT or PT physical volume.

b. Provides a detailed formatted dump of the non-image records and the prefix and suffix data of a small sample of the image records.

c. Gives an indication of whether or not the number of records and files are in the order as advertised by the file pointer records on the tape.

d. Reports for each band the total number of all replicated lines, the maximum number of contiguously replicated lines and the last line number of such a swath.

e. Displays a count of the records in which "read" retries occurred and the maximum number of retries for any record.

6.8.5.5.2 Radiometric Correction

For monitoring the thematic mapper instrument, TIPS provides the capability to extract calibration lamp, shutter and thermal band calibration source minor frames from raw data. The TIPS provides the capability for the recording of these minor frames on CCT, together with spacecraft time for the corresponding major frame. To facilitate evaluation, the calibration data thus captured can be displayed by the PLOTCAL software. In addition, the histograms of the raw input data can be examined using the PLOTHIST software.

Should the calibration data indicate a significant change in sensor response, the radiometric correction parameters can be updated using the parameter update software. This was a TM radiometric correction R&D task that created support software for updating radiometric correction parameters. This package is not a part of the production software, but is a very valuable tool for maintaining the radiometric correction fidelity. The reason such software is necessary is that with time the sensor characteristics change. Radiometric correction is very dependent on sensor related parameters such as nominal cal values, thresholds, windows, etc. These then need to be modified. The sheer volume of numbers rules out a manual effort. This package provides a way to compute and update radiometric correction parameters.

6.8.5.5.3 Engineering

Numerous tools were developed to enhance the engineering capabilities of the TIPS. They were:

a. EWOS - Create and edit engineering work orders.
b. ETOP - Create and edit engineering TIPS operational parameter files.
c. EDITTSP - Edit TIPS short-term parameter files.
d. EDITTLP - Edit TIPS long-term parameter files.
e. DUMPSCD - Dump systematic correction data files.

6.9 GROUND SEGMENT PERFORMANCE

The performance of the Ground Segment is discussed separately for MSS and TM imagery. Specific paragraphs describe the performance in relation to: (1) radiometric corrections, (2) geometric corrections, (3) system throughput, and (4) processing turnaround times. In addition, there is a discussion of the Automatic Cloud Cover Assessment (ACCA) in relation to TM imagery.

6.9.1 MSS DATA PROCESSING

The following four paragraphs discuss radiometric corrections, geometric correction, system throughput and processing turnaround times for processing of MSS data.

6.9.1.1 Radiometric Performance

This subparagraph includes two topics: post-launch calibration of the sensors, and Ground Segment correction performance. The former summarizes the major steps taken to remove sensor striping. The second presents quantitative results on performance, which can be compared to requirements.

6.9.1.1.1 Post-Launch Calibration

Post-launch calibration of the instruments is necessary as the in-orbit behavior of the sensors is considerably different from the ambient ground environment (where all the pre-launch parameters are determined arbitrarily). Also, the sensor characteristics change with time, necessitating further updates.

Post-launch calibration for MSS data processing consists of updating some or all of the following parameters:

a. Nominal Cal values and Acceptance Window. These parameters are used to validate the incoming cal data which is used to compute the detector response functions (gain and bias values).

b. Multiplicative and Additive (M&A) constants. These are used to fine tune the response functions to reduce sensor striping.

c. Rmin and Rmax. The radiance range over which the detector values are calibrated.

For Landsat 4 MSS, the M&A modifiers were updated on August 1 and August 22, 1982. The first was required because of the 6% slide in response of the photomultiplier sensors in bands 1, 2 and 3 when exposed to the space environment. The second was required to adjust for sensor drifts.

The Rmax values for bands 1 and 3, which define the upper radiance range for those bands, were modified on August 17, 1982. The pre-launch values that had been selected turned out to be greater than the radiance values at which some detectors saturated. This caused striping in high radiance scenes. The change was implemented as a modification to the M (multiplicative) values. Thus the pre-launch regression components did not have to be regenerated.

The Cal Wedge Nominal values were also updated twice. The first time was two weeks after launch on July 30, 1982, to again account for the change from ground to flight conditions. The second update was made on August 26, 1982, to only Detector 9 nominal values. This channel was exhibiting large swings in its gain. In addition to the nominal values, the Cal Wedge Acceptance Window was also changed from 5 to 6 quantum levels.

The above updates refer to the PCL (prime lamp, compressed mode, low gain) mode of operation of the MSS sensor. This is the primary mode of operation of the sensor, as more than 99% of the data is gathered with this mode. Post-launch calibration of modes PCH (prime, compressed, high) and PLL (prime, linear, low) was also done in December 1982, just before turnover of the system to NOAA.

For Landsat 5, the PCL and PCH mode post-launch calibration parameters were determined. These were delivered in June 1984 to NOAA/CSC for installation. These consisted of M&A updates, and new Cal Wedge Nominal values.

6.9.1.1.2 <u>Performance Evaluation</u>

The radiometric correction performance is evaluated at the band level on the archival product. The requirement is that the system correct the six channel values in each band to within $\pm$ 1 quantum level in a scan, 99.9% of the time.

The quantity used to check this requirement is the range check value, which is the range of detector radiances for a scan after removal of scene content effects. Scene content adjustment is made by subtracting a seven-line window average from the line mean for each detector. Any variation within band detectors due to changing scene radiance is then minimized, and a more accurate measure of true band striping can be derived. The range check value is printed in the PEPG radiance evaluation report only if a range check exception occurred; i.e., only if the range check value exceeded the range check limit of 2. A count of these range check exceptions for a large number of scans is an indicator of the radiometric performance. Another report value used to measure the radiometric correction is the radiometric quality indicator (RQI) which is the average of the scan range check values over the entire scene. Requirements are met if this value is less than 1.33 quantum levels.

Typical examples of RQI are shown in Table 6.9-1. There were no range check exceptions over the 2400 scans evaluated. That is, all scans were corrected to within specifications. In all cases, the average RQI values are considerably less than 1.0, which shows that adequate correction is well within the required capability.

Table 6.9-1. Average RQI Values. Units are Quantum Levels

Scene	Band 1	Band 2	Band 3	Band 4
1	0.35	0.43	0.64	0.33
2	0.34	0.34	0.61	0.31
3	0.47	0.31	0.49	0.22
4	0.52	0.35	0.21	0.28
5	0.28	0.32	0.94	0.14
6	0.68	0.31	0.79	0.19

6.9.1.2 MSS Geometric Performance

The specification for temporal registration performance for the Landsat MSS system has been interpreted to mean that features of the registrant image and the reference image shall be co-located in cross-track and along-track axes to

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within 0.3 IFOV 90 percent of the time. The requirement for geodetic rectification is that features of an image registered to a map be co-located in both axes with features of a "perfect" map (i.e., no map error) within 0.5 pixel, 90 percent of the time. The IFOV for MSS is approximately 83 meters.

Several tasks and analyses made significant contributions towards the achievement of the final registration accuracy of the MSS Image Processing System (MIPS). The implementation of the line length correction, with line lengths determined to subpixel accuracy (a significant departure from the Landsat 2, 3 era), reduced the image internal distortions near sweep end points from a worst case of $\pm$ 0.48 pixels to $\pm$0.04 pixels. Post-launch calibration of data editing and validation parameters, MSS filter control parameters and the instrument alignment parameters made significant contributions to the system geometric accuracy. The most significant contribution to improved geometric performance was the calibration of the MSS scan mirror profile. This calibration was achieved using routine outputs of the system for scenes with an abundance of well-registered geodetic control points (GCPs).

Table 6.9-2 summarizes the MSS geometric performance accuracy for Landsat 4, 5 scenes with ten or more well-distributed GCPs.

The temporal registration accuracy was, in general, estimated from system output using error estimation techniques. For a few instances, it was measured directly by comparing two geodetically corrected scenes. 32 by 32 control point chips were extracted from one scene and 64 by 64 control point neighborhoods (CPNs) were extracted from the other scene. The offsets of the control point chips registration locations from the expected locations in the CPNs along with the accuracy of CP registrations, provide the data for computing a direct measure of the temporal registration accuracy. A comparison of the two approaches showed that while the results from the error estimation method were consistent with the direct measurements, the former approach gave higher estimates of registration errors. The data in Table 6.9-2 reflect the more conservative estimates of the system accuracy.

Table 6.9-2. MSS Registration Accuracy*

		Pre-Cal Accuracy (90%)		Post-Cal Accuracy (90%)		System Accuracy Requirement	
Sat. #	Direction	Temporal Regis-tration	Geodetic Regis-tration	Temporal Regis-tration	Geodetic Regis-tration	Temporal Regis-tration	Geodetic Regis-tration
4	Cross-Track	0.41	0.79	0.29	0.37	0.3	0.5
	Along-Track	0.25	0.40	0.25	0.34	0.3	0.5
5	Cross-Track	0.45	0.50	Data Unavailable		0.3	0.5
	Along-Track	0.27	0.35	Data Unavailable		0.3	0.5

* All data values are in units of MSS IFOV = 83 meters.

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The geodetic registration accuracy, E_g, was obtained from the temporal registration accuracy, E_t.

$$E_g^2 = E_t^2 + E_d^2$$

where E_d is the estimate of the pointing error corresponding to the probable bias in system state determination caused by the noise in the GCP location information and is given by:

$$E_d^2 = d^2 * n/2N$$

Here, d is the GCP location designation error, n=6 is the number of system state vector elements and N (assumed to be 10 for the purpose of Table 6.9-2) is the number of GCPs successfully registered. The history of the 90% designation errors for Landsat 4 is summarized in Table 6.9-3. For Landsat 5, the final post-cal Landsat 4 values are substituted in estimating geodetic registration accuracy.

Table 6.9-3. MSS Control Point Designation Error (Landsat 4)

Direction	Unfiltered Designation 90% Error	Filtered Designation 90% Error (Pre-Cal)	Filtered Designation 90% Error (Post-Cal)
Cross-Track	0.82	1.23	0.41
Along-Track	0.82	0.58	0.41

The geodetic registration accuracy was evaluated using a direct approach (see paragraph 6.9.2.2) and was shown to be consistent with the preceding method.

For Landsat 4, from Table 6.9-2, it is apparent that both temporal and geodetic registration accuracy requirements are fully met. For Landsat 5, post-cal performance data is not available at present. However, comparison with Landsat 4 data suggests that when the data base is updated to reflect post-launch calibration, Landsat 5 MSS will also meet the prescribed geometric accuracy.

6.9.1.3 MSS Throughput

During the Buy-off Demonstration in October 1982, the system was shown to have the capability to throughput 200 scenes per day within 85 percent of a two-shift day. To meet the 200 scenes per day requirement, each MIPS string must be capable of 67 scenes in 13.6 hours. The demonstration was accepted.

6.9.1.4 MSS Processing Turnaround Times

Turnaround times for MSS data processing were determined during the October 1982 Buy-off Demonstration. Information to establish actual Ground Segment performance for turnaround time was derived by tracking tapes as they progressed though the system. The most significant observation that can be made is that about 75 percent of the tapes were processed in less than 48 hours, whereas others took over 48 hours. Detailed studies of the progress of the tapes through the system indicated that for those tapes exceeding 48 hours the causes of the delays were procedural in nature and can be corrected. Operational procedure changes were proposed to make it possible to meet the 48-hour turnaround requirement.

6.9.2 TM DATA PROCESSING

The following five paragraphs discuss radiometric correction, geometric correction, system throughput, processing turnaround times, and automatic cloud cover assessment for TM data processing.

6.9.2.1 TM Radiometric Performance

Like its MSS counterpart, this paragraph also reviews the major post-launch calibration efforts and quantifies the radiometric performance.

6.9.2.1.1 Post-Launch Calibration

The TM radiometric correction is much more dependent on parameters than are the MSS algorithms. This is partly because of the increased number of channels and the addition of the thermal band, but mainly because of the more complex online correction that takes place. Examples of parameters are data extraction MNFs (minor frames), nominal values, acceptance windows, thresholds, regression weights, lamp radiances and thermal band coefficients. Like MSS, an initial set of values was determined for both Landsat 4 and 5 from pre-launch data. Some of the parameters were updated soon after the respective satellite launches, to account for flight conditions. These consisted mainly of changes to nominal cal values and data extraction MNFs. Updates to the other parameters were made during the subsequent TM R&D period to enhance performance. The remainder of this section discusses five updates of major significance. The changes apply to both Landsat 4 and 5 data processing, unless otherwise indicated.

6.9.2.1.1.1 LBR Tables

The generation of 241 mm film products makes use of LBR gamma tables. In July 1983, new band-dependent tables were installed. These were designed to bring out the best contrast in the imagery. This was a joint effort by NASA, EDC and GE.

6.9.2.1.1.2 Thermal Band Radiance Range

The thermal band data was originally calibrated to a temperature range of 260 to 320°K. This resulted in many dark scenes over high latitudes in winter. The calibration range was therefore expanded to 200 to 340°K in September 1983. This change also made the TIPS thermal band processing compatible with Scrounge.

6.9.2.1.1.3 Reflective Bands Radiance Range

In January 1984, new radiance ranges were installed for the reflective bands. This set of Rmin and Rmax values was provided by the NASA Science Office. It was implemented after exhaustive testing to check its impact on ACCA, LBR tables and CP processing.

6.9.2.1.1.4 Light Leak

Landsat 5 TM contains a light leak in the shutter flag, between the edge of the lenses and the flag body. This results in a secondary pulse in the calibration region. Analysis showed that this secondary pulse would not affect the correction, except for state 8 for all reflective bands, and state 7 for band 5. By changing the extraction thresholds and the weights for these states in the parameter file, the effect of the light leak was minimized. This change was made in March 1984.

6.9.2.1.1.5 Absolute Radiometric Correction

The absolute radiometric correction of TM data was evaluated using pre-launch Landsat 5 integrating sphere data, and in-orbit Landsat 4 and 5 overlap data of March 15, 1984. As a result of the analysis, two changes were made. First, the regression algorithm was changed from a weighted to an unweighted scheme. This consisted of both software and parameter changes. Second, lamp radiances for band 3 (Landsat 5 only) were computed from in-orbit data, to correct for the difference between the gains for odd and even channels. These changes went into effect July 1984.

6.9.2.1.2 Performance Evaluation

The algorithm used to measure the TM relative radiometric correction performance is similar to that used for MSS. The range of the 16 channel values is computed on a scan basis on the HDT-AT data. This is done by the range check option in the TM data quality (TDQ) package. The requirement is that the system correct to $\pm$ 1 quantum level out of 256. This means the scene content removed range for each scan shall never exceed 2 quantum levels.

Tables 6.9-4 and 6.9-5 are typical examples for Landsat 4 and 5 performance. The Landsat 4 correction is as of November 1983, while the Landsat 5 numbers date from July 1984. The tables show average RQI numbers over areas selected from different scenes. Numbers in parentheses indicate the number of scans that exceeded the two quantum level limit. The areas indicated were selected from several different scenes.

Table 6.9-4. Landsat 4 TM Radiometric Correction

(The Offline Radiometric Quality Indicators (RQI) units are quantum levels. Numbers in parentheses indicate the number of scans that exceeded the 2 quantum level limit.)

AREA	# OF SCANS	BANDS						
		1	2	3	4	5	6	7
1	32	1.33	.60	.79	.38	.90	.23	3.95 (7)
2	26	1.21	.47	.79	.60	.61	.26	1.91 (6)
3	32	1.38	.65	.76	.35	.85	.22	3.60 (32)
4	32	1.30	.42	.64	.58	1.01	.24	.89
5	32	1.23	.45	.77	.54	.87	.30	1.33 (10)
6	32	1.21	.50	.79	.49	.85	.26	.97
7	32	1.21	.43	.70	.33	.69	.24	1.54 (2)
8	32	1.26	.52	.64	.33	.70	.23	.87
9	32	1.37	.65	.81	.37	.74	.31	.92

Table 6.9-5. Landsat 5 TM Radiometric Performance
(There were no range check exceptions.)

AREA	# OF SCANS	BANDS						
		1	2	3	4	5	6	7
1	32	0.38	0.69	0.40	0.37	0.64	0.30	0.47
2	32	0.48	0.66	0.53	0.40	0.49	0.26	0.43
3	32	0.87	0.76	1.71	0.36	0.56	0.29	0.43
4	32	0.58	0.71	0.52	0.57	0.58	0.40	0.44
5	32	0.60	0.62	0.52	0.62	0.53	0.37	0.51
6	13	0.72	0.66	0.60	0.56	0.52	0.37	0.49

For Landsat 4, only some band 7 data are is not being corrected to specification. This is only for scenes with many low radiances values, such as water. The reason is that channel 7 in band 7 is twice as noisy as the other channels. This causes much low radiance data to fall below the DC restore level, which results in the scene content correction process diverging. Limitation schemes to the SCC process have been implemented lately, which reduce this divergence. Updated numbers for Landsat 4 are not available. Landsat 5 correction is well within requirements and all channels are behaving properly.

6.9.2.2 TM Geometric Performance

The specification for temporal registration performance for the Landsat TM system has been interpreted to mean that features of the registrant image and reference image shall be co-located in cross-track and along-track axes to within 0.3 IFOV 90 percent of the time. The requirement for geodetic rectification is that features of an image registered to a map be co-located in both axes with features of a "perfect" map (i.e., no map error) within 0.5 pixel 90 percent of the time. The IFOV for TM is approximately 30 meters.

The compliance of the TM geometric performance with system specifications was made possible by several significant enhancements to the ground processing system beyond the optimization of the parameters related to the geometric correction process. The enhancements to the radiometric correction process were crucial to the improved correlation surfaces that lead to improved subpixel registration accuracy for the control points (CPs). Calibration of the alignment of the primary focal plane bands with the bands of the cold focal plane removed a significant source of error in the control point locations as the control point library contains chips extracted from bands of both focal planes. This calibration amounted to alignment corrections of 0.7 pixels along-track and 0.2 pixels cross-track.

Table 6.9-6 summarizes the results of the direct measurements of temporal and geodetic registration accuracy for Landsat 4. Tables 6.9-7 and 6.9-8 summarize the registration accuracy assessment for Landsat 5 by the methods of error estimation and direct measurements, respectively.

Table 6.9-6. Temporal Registration and Geodetic Rectification Performance of Landsat-4 by Direct Measurement

TEMPORAL REGISTRATION

PATH/ROW		DAY 1	DAY 2	NUMBER OF POINTS	REGISTRATION ERROR CROSS-TRACK (PIXELS, 90%)	REGISTRATION ERROR ALONG-TRACK (PIXELS, 90%)
17	35	123	155*	24	0.30	0.32
17	36	123	155*	20	0.35	0.31
17	36	123	187	34	0.16	0.25
			WEIGHTED MEAN		0.25 ± 13%	0.29 ± 13%

GEODETIC RECTIFICATION

PATH/ROW		DAY 1	DAY 2	NUMBER OF POINTS	REGISTRATION ERROR CROSS-TRACK (PIXELS, 90%)	REGISTRATION ERROR ALONG-TRACK (PIXELS, 90%)
17	35-39	155	155*	107	0.52	0.56
23	36-37	101	101*	23	0.46	0.32
27	32-33	97	49*	37	0.47	0.55
			WEIGHTED MEAN		0.50 ± 8%	0.52 ± 8%

*Reference scene

Table 6.9-7. Temporal Registration and Geodetic Rectification Performance of Landsat 5 by the Method of Error Estimation

		REGISTRATION ERROR			
	NUMBER OF	CROSS-TRACK (PIXELS, 90%)		ALONG-TRACK (PIXELS, 90%)	
SCENE ID	CPs	TEMPORAL	GEODETIC*	TEMPORAL	GEODETIC*
5T0240320130	11	0.33	0.52	0.34	0.53
5T0240330130	11	0.28	0.49	0.22	0.46
5T0240340130	24	0.30	0.50	0.30	0.50
5T0240350130	20	0.27	0.48	0.30	0.50
5T0240360130	17	0.25	0.47	0.39	0.56
INTERVAL	83	0.29 ±11%	0.49	0.32 ±11%	0.51

* A nominal E_d = 0.4 pixel in each direction has been used, and this far exceeds the measured E_d for LS-4 CPs.

Table 6.9-8. Temporal Registration and Geodetic Registration Performance of Landsat 5 by Direct Measurement

TEMPORAL REGISTRATION

PATH/ROW	DAY 1	DAY 2	NUMBER OF POINTS	REGISTRATION ERROR CROSS-TRACK 90% ERROR (PIXELS)	REGISTRATION ERROR ALONG-TRACK 90% ERROR (PIXELS)
24/34	130	146	13	0.19 ± 28%	0.22 ± 28%

GEODETIC REGISTRATION

PATH/ROW	DAY 1 (LS5-SCENE)	DAY 2 (LS4 REF SCENE)	NUMBER OF POINTS	REGISTRATION ERROR CROSS-TRACK 90% ERROR (PIXELS)	REGISTRATION ERROR ALONG-TRACK 90% ERROR (PIXELS)
24/34	7/9/84 (130)	9/30/82	20	0.43 ± 22%	0.38 ± 22%
24/13	130	9/30/82	13	0.57 ± 28%	0.63 ± 28%
INTERVAL COMPOSITE	130	9/30/82	33	0.50 ± 17%	0.49 ± 17%

The system-generated error estimates are based on the RMS control point residuals and the estimated pointing error $\vec{E}_d$ that corresponds to the bias error in the system state vector estimate caused by the noise in CP location and is given by:

$$\vec{E}_d = HPH^T$$

Here H is the measurement matrix and P is the covariance matrix driven by the CP location noise. For temporal registration, the source of the noise is correlation noise and the random image error. For geodetic registration, the correlation noise is replaced by a much larger noise - the CP designation error.

The direct measurement approach for TM temporal registration error assessment was the same as for MSS (see paragraph 6.9.1.2). The direct measurement approach for geodetic registration error assessment used the CP Library Build (CPLB) process. It consisted of designating control points in corrected imagery using a Zoom Transferscope to overlay the imagery onto a map. The offsets of designated locations from the system predicted locations based on known longitude/latitude of the CP were determined.

The geodetic error E_{gx} was then computed from the 90% offset error E_{OFF-X} as follows:

$$E_{gx}^2 = E_{OFF-x}^2 - D_x^2$$

The CP designation 90% error D_x was computed from the CPLB filtered RMS residuals:

$$D_x^2 = RMS_x^2 * 1.645^2 - E_{tx}^2$$

where E_{tx} is the 90% temporal registration error of the system.

From the tabulated results, it is clear that both methods of registration error assessment are consistent with each other and that both Landsat 4 and Landsat 5 TM systems meet the geometric accuracy requirements.

6.9.2.3 TM Throughput

Data throughput capability for TM processing was documented with two demonstrations. The first demonstration was conducted during October 1983 and the second during July and August 1984.

During October 1983, TIPS demonstrated the capability to process, at a sustained level, 12 scenes per day to film and two scenes per day to CCTs over a 10-day period. Scene throughput demonstrated was the actual processing of averages of 12.8 scenes per day to HDT-P, 12.5 scenes per day to film, and 2.1 scenes per day to CCTs.

TIPS specifications called for the production capability to be increased to reach daily thematic mapper image totals of: (1) 100 scenes processed through TAG (HDT-A tape), (2) 50 scenes processed through TIG (HDT-P tape), (3) 50 scenes recorded on 241 mm film, and (4) 10 scenes recorded on computer compatible tape (CCT-A or CCT-P). In addition, there was a requirement to generate control point chips at an average rate of 100 chips per day. The ability to meet these higher throughput rates was demonstrated during the period July 30, 1984 through August 8, 1984. All specified daily production rates were met, or exceeded, during this demonstration of sustained performance.

With each of the TIPS processes (TAG, TIG, Film, or CCT generation) the time required per scene varies inversely with the number of scenes per interval. Tables 6.9-9 and 6.9-10 illustrate the relationships between interval size and time for processing one scene with each of the four TIPS processes. These tables were generated from data extracted from the Production Logs for the demonstration period. A regression equation relating total processing time to interval size was developed for each process. Table 6.9-9 shows the average number of minutes required to process an interval containing a given number of scenes, while Table 6.9-10 shows the average number of minutes required to process each scene according to interval size.

Table 6.9-9.
Interval Processing Times
during August 1984
TIPS Demonstration
(minutes per interval)

SCENES PER INTERVAL	TAG	TIG	TFG FILM	TFG CCT
1	14.9	31.1	21.7	35.4
2	18.1	38.7	30.8	59.8
3	21.3	46.3	39.9	84.2
4	24.4	53.9	49.0	
5	27.6	61.5	58.1	
6	30.8	69.1	67.2	
7	34.0	76.7	76.3	
8	37.2	84.3	85.4	
9	40.3	91.9	94.5	
10	43.5	99.6	103.6	
11	46.7	107.2	112.8	
12	49.9	114.8	121.9	
13	53.1	122.4	131.0	
14	56.2	130.0	140.1	
15	59.4	137.6	149.2	
16	62.6	145.2	158.3	
17	65.8	152.8	167.4	
18	69.0	160.4	176.5	
19	72.1	168.0	185.6	
20	75.3	175.7	194.7	
21	78.5	183.3	203.9	
22	81.7	190.9	213.0	
23	84.9	198.5	222.1	
24	88.0	206.1	231.2	
25	91.2	213.7	240.3	

TAG: $T = 3.18\, n + 11.72$

TIG: $T = 7.61\, n + 23.45$

FILM: $T = 9.11\, n + 12.54$

CCT: $T = 24.38\, n + 11.05$

T = minutes per interval
n = scenes per interval

Table 6.9-10.
Scene Processing Times
during August 1984
TIPS Demonstration
(minutes per scene)

SCENES PER INTERVAL	TAG	TIG	TFG FILM	TFG CCT
1	14.9	31.1	21.7	35.4
2	9.0	19.3	15.4	29.9
3	7.1	15.4	13.3	28.1
4	6.1	13.5	12.2	
5	5.5	12.3	11.6	
6	5.1	11.5	11.2	
7	4.9	11.0	10.9	
8	4.6	10.5	10.7	
9	4.5	10.2	10.5	
10	4.4	10.0	10.4	
11	4.2	9.7	10.2	
12	4.2	9.6	10.2	
13	4.1	9.4	10.1	
14	4.0	9.3	10.0	
15	4.0	9.2	9.9	
16	3.9	9.1	9.9	
17	3.9	9.0	9.8	
18	3.8	8.9	9.8	
19	3.8	8.8	9.8	
20	3.8	8.8	9.7	
21	3.7	8.7	9.7	
22	3.7	8.7	9.7	
23	3.7	8.6	9.7	
24	3.7	8.6	9.6	
25	3.6	8.5	9.6	

TAG: $t = 3.18 + \frac{11.72}{n}$

TIG: $t = 7.61 + \frac{23.45}{n}$

FILM: $t = 9.11 + \frac{12.54}{n}$

CCT: $t = 24.38 + \frac{11.05}{n}$

t = minutes per interval
n = scenes per interval

The TM Ground Segment design provides sufficient reserve capability to survive and fully recover from a major data-loss occurrence. (The system recovered from a loss of 402 archival scenes, 62 scenes on film, and 20 scenes on CCTs because of a TIPS-1 TAG problem during the demonstration.) Actual performance exceeded 120 percent specified performance.

6.9.2.4 TM Processing Turnaround Times

Data turnaround capability for TM processing was documented with two demonstrations. The first demonstration was conducted during October 1982 and the second during July and August 1984.

During the October 1983 demonstration of the TIPS, the timeline requirement to process data within 48 hours was met for 70 percent of the products. The demonstrated turnaround time averaged 43.88 hours.

During the second TM Ground Segment Demonstration, performed in August 1984, it was shown that the TM Ground System can process data on a sustained basis within prescribed timelines. A total of 95 percent of all demonstration scenes were processed within 48 hours.

Quality of output data was maintained during the second demonstration at established levels of acceptability. Film acceptance rate was 97 percent, while CCT acceptance rate was 98 percent. System availability was 95 percent.

6.9.2.5 ACCA

The evaluation of ACCA scores for Landsat 5 images was performed after radiometric calibration on Landsat 5 data had been completed. In order to evaluate its impact on ACCA thresholds to ensure the accuracy of ACCA scores, 241 mm films were used to measure the cloud-cover percentage. A scene was divided into four quadrants and each quadrant further divided into 100 squares, with each square representing one percent of area coverage. Based on the contents of bands 3, 5 and 6, the cloud cover was measured manually by counting the number of cloud cover squares to obtain scores for each quadrant. Then, these scores were compared to the corresponding ACCA scores from TAG quality assurance reports. The current thresholds are sufficient to produce a reasonable cloud cover percentage for Landsat 5 data.

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6.10 OUTPUT PRODUCTS

The output products of the Landsat Ground Segment are archival tapes, 241 mm film and computer compatible tapes.

6.10.1 ARCHIVAL TAPES (A-TAPES)

A-tapes are high density tapes, radiometrically corrected, with tables included to permit geometric corrections to any of three map projections: Space Oblique Mercator, Universal Transverse Mercator or Polar Stereographic. These tapes are maintained in NASA or NOAA facilities.

6.10.2 241 MM FILM ROLLS

241 mm film rolls contain first-generation, fully-corrected, positive film scenes. This film size provides an image/ground scale of 1:1,000,000; i.e., 1 millimeter on the film represents 1 kilometer on the ground. These are sent to EROS Data Center in Sioux Falls, South Dakota, a Department of Interior facility, from which any customer may purchase a print.

6.10.3 COMPUTER COMPATIBLE TAPES

Computer compatible tapes (CCTs) are either fully corrected tapes (CCT-PT), or radiometrically corrected tapes (CCT-AT) with tables included for geometric corrections to two map projections. Four TM CCTs (one for each quadrant) are provided for each 185 X 170 kilometer scene from either the A-tape or from the fully corrected P-tape, in all seven spectral bands. These tapes are sent to EROS Data Center, from which copies may be purchased by any customer.

6.10.4 QUALITY ASSURANCE (QA)

QA was provided for TM products by visual inspection of each 241 mm film image produced and by examination of computer printouts for other products. Those products failing to meet established quality levels (specified in SOPs) were either regenerated or cancelled. See Figure 6.0-2.

Improvements were made steadily, so that in the last few months of the contract, no rejections were necessary for video (radiometric or geometric) causes. Incidents of severe pixel noise were shown to be caused by: 1) ground station reception at elevation angles less than 8° (i.e., range to spacecraft greater than 2300 kilometers), or within 8° of the Sun line; and 2) known sources of interference, mainly Defense Department radars.

All TM 241 mm film rejected in the past few months of the contract were attributable to non-video causes: density, dimension and line-start of the laser beam recorder.

6.10.5 OUTPUT STATISTICS

Refer to paragraph 4.5.3 in Volume I of the Final Report for an extensive discussion of the number of scenes acquired by TM through 1983, the involved ground stations and data evaluations of the TM and MSS products. User judgments of the TM quality were: radiometric - "quite good"; geometric - "remarkably good"; and application potential - "most useful".

As of August 31, 1984, the TM instrument had collected, via Landsat 4 and Landsat 5, a total of 22,871 scenes. The area of the scenes acquired is 719 million square kilometers, an area nearly five times the area of all land masses on Earth. 13,927 of these scenes have been converted to archival tapes and stored in NASA/NOAA facilities. 4093 scenes on 241 mm film have been shipped to the EROS Data Center, plus 856 (sets of four quadrant tapes) CCTs. Table 6.10-1 shows details.

Table 6.10-1. TM Operations Through August 1984

Operation	Landsat 4	Landsat 5
Scenes Acquired (R-Tape)	7613	15258
Scenes Archived (A-Tape)	1803	12124
Scenes to 241 mm Film	1468	3617
241 mm Scenes Shipped	1450	2643
Scenes to CCT-P	277	698
CCT-Ps Shipped	233	519
Scenes to CCT-A	47	85
CCT-As Shipped	34	70

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6.11 LESSONS LEARNED

Looking back objectively, hindsight provides judgments and observations that may enhance the performance and quality of subsequent programs. The items described in this section of the report are presented for that purpose.

6.11.1 PROGRAM MANAGEMENT AND SYSTEMS ENGINEERING

a. The development of a close working relationship with NASA managers was instrumental in focusing attention on key problem areas, establishing priorities and resolving critical issues to achieve program objectives.

b. In responding to the challenge of building a "production" data processor of data from an R&D instrument, the performance of which was undefined, an extraordinary amount of attention and planning was given to key processes and the way they would interact. TIPS was designed to be modular to facilitate the modification of major functions or processes with minimal impact to others, as instrument and ground processing performance became better understood and practical limitations defined.

c. A comprehensive engineering and interactive capability was included to facilitate development as well as data and process analysis. As system needs became clearer during TIPS implementation, this capability was redefined and improved.

d. The use of Program Directives to control funding and document requirement changes provided an effective means to control the program.

e. The Cost Performance Measurement System (CPMS) provided an effective tool to measure cost and schedule performance.

f. The preparation of a Ground Segment Management Plan provided a means to define organizational responsibilities and publicize them.

g. Completed definition of external and internal interfaces is critical to on-schedule project development. This includes generation of interface control documents (ICDs), formal ICD approval by all interested parties, and rigid control of post-approval ICD change.

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h. Completed definition of overall system specifications (e.g., Ground Segment specification) is mandatory before development proceeds beyond a severe breakage point.

i. The detailed effort spent defining building layout, power distribution, air conditioning and ground distribution minimized the potential problems after equipment installation.

j. The use of an Engineering Review Board to discuss initial requirements, test plans, test results, hardware and software changes provided an effective tool to discuss the technical merits of an issue, schedule activities and encourage customer participation in the development process.

k. The rebaseline, completed in September 1980, placed increased emphasis on cost and schedule control. As a result, several new actions were introduced:

   1) Cost Performance Measurement System (CPMS) allowed each cost account manager to track his cost performance against schedule. Monthly reports were available for trends and were given to NASA.

   2) Weekly review of financial data by contractor, program manager and NASA managers highlighted problem areas and forced solutions.

   3) Increased emphasis was placed on organizational responsibilities and budgets and other changes controlled by Program Directives.

l. In turnover to NOAA, important considerations are:

   1) A well thought-out plan, agreed to in advance, was crucial to the successful turnover.

   2) The ability of the incoming contractor to capture incumbent personnel and the use of a small engineering core team allowed activities after turnover to be successful.

   3) Use of video tapes for training was extremely successful as it allowed flexibility for the students to review material daily and to provide a library of the original instructor's knowledge.

m. Undersized DRRTS CPU/memory requirements result in:

   1) Inability to meet concurrent requirements for DECNET transfer to MMF with the directory generation.

   2) Need to drop creation of image data quality files during the directory generation process to make the process work.

n. DRRTS software performance requirements must be clearly stated. Neglect of this resulted in many substantial revisions to the MMF service routines.

o. The key to the successful operations of the MSS portion of the Ground Segment is adequate resources. These include:

   1) Financial - adequate funding to perform the mission, while still being able to use flexibility for other activities
   2) Schedule - adequate time to perform the necessary tasks
   3) Personnel - the key technical and operational contributors and leaders remained on the program through operations and turnover
   4) Hardware - there were extra resources to accommodate operations activities, maintenance of both hardware and software, and additional development of changes.

p. Early emphasis on the importance of operational concepts during the system development was required to ensure ease of operations.

q. Management push, both from the NASA Project Office and from GE, to force turnover of the system to operations was necessary to ensure adequate time for training and to start exercising the system in an operational manner. The latter uncovered problems not found during integration and test.

r. Combined responsibility for operations and remaining development under one manager allowed the proper resources and priorities to be assigned.

s. The use of written directions and action items by the Mission Operations Manager ensured that GE was responding to well-considered and approved NASA direction.

t. The use of video tapes for training was extremely useful for cross-training and refurbishment of knowledge.

u. Daily formal reports on operations progress and problems focused resources and fixed priorities in a timely fashion.

6.11.2 HARDWARE DEVELOPMENT

a. Early use of technical experts in developing design and manufacturing guidelines for the complex, high-speed equipment was valuable, particularly since the first assemblies were to be used for the system.

b. The use of wire-wrap concepts allowed modifications for engineering changes (upgrades and errors) at relatively low cost.

c. A greater emphasis on using off-the-shelf parts for key assemblies (backplanes, devices) could have reduced the technology risks. In some areas, e.g., MMF, where off-the-shelf items were used nearly 100%, a stable development and operations environment existed.

d. Rigid adherence to preventive maintenance schedules resulted in a reliable hardware system, where outages were infrequent and of short duration.

e. In a long-development program, upgrading vendor supplied ADP hardware is required. This keeps pace with the technology, helps computer professional employee morale, results in higher reliability and lower life cycle maintenance costs.

f. Transportable Ground Station. The TGS was a highly successful project, delivered on time and meeting or exceeding all of its performance requirements. This success is directly attributable to the skill, experience, and cooperation of the NASA, SA, and GE personnel involved in its design and implementation. This is a lesson which can never be relearned too often. Other lessons learned in this development were:

   1) Careful implementation of redundancy in the system and the careful selection of the test equipment complement which provides built-in end to end testing and short loop testing, ensures the capability to maintain system performance and system availability at a high level of readiness.

   2) The most severe problem experienced in the TGS project resulted from the failure of the antenna foundation studs to be properly positioned in the concrete by the facilities subcontractor even though a template had been supplied for this purpose. This problem was detected in November of 1980 and considerable effort was expended in resolving the problem. The foundation is steel reinforced concrete, 22 feet in diameter, four feet deep.

Twelve anchor bolts one and one-fourth inch in diameter by 27 inches in length, with 8 inch square welded steel baseplates were to be embedded in the concrete on a 70 inch bolt circle. These studs were to extend above the concrete four and one-half inches for attachment of the antenna base extension. Efforts to reposition the bolts included bending, cutting, addition of couplings, an additional layer of concrete, and testing of the repairs. It was discovered at the initial attempt to install the base extension that the bolts still were not located within the required tolerances. This required counterboring the base extension holes and the design of steel plate washers in order to assure suitable stiffness. During the subsequent installation of the base extension it was found that one of the bolts would not survive the required torque. Finally, twenty-four additional studs were installed through the base into the concrete using parabond anchors. This was followed by a weekly test program lasting a year to verify the integrity of the repair. In retrospect, the lesson learned is that the initial reaction when the problem was first detected of tearing out and rebuilding the foundation would probably have been the most satisfactory and cost effective solution to the problem.

3) The TGS test capability includes test couplers in the sum channels after the feeds to permit injection of test signals as one means of verifying system performance. The signal is upconverted for X-band using the same local oscillator as the X-band downconverter. A failure of the local oscillator to lock on frequency was masked in this test mode as the oscillator drift was common to both the up and down conversion channels. The problem was detected by attempting to lock on to the boresight tower test signal. The obvious solution to this problem would be the use of separate local oscillators for up and down conversions.

4) Parametric amplifiers were used in both the C-band and in the S-band channels in order to achieve the required G/T

specifications of the system. During the course of the design GaAs FET low noise amplifier technology advanced to the state that equivalent G/T performance could be met in S-band using GaAs FET LNAs, and X-band LNAs which were within .8 dB of the para-amp performance. Consequently, GaAs FET LNAs where used as spares for the para-amps at considerable savings in cost. These amplifiers have been used temporarily to replace failed para-amps with little or no noticeable reduction in overall system performance, because of system margin. Current X-band LNAs are available with performance within .3 dB of the para-amp specifications. Repairs to the para-amps should be made only as long as the cost of repair is less than the cost of the GaAs FET LNAs with similar performance. The FET LNAs are far more reliable than the para-amps.

5) Early in the TGS design cycle, heaters were recommended for the antenna reflector. This recommendation was rejected because of the additional cost involved and because the planned use of the TGS at that time was not primary US data collection source for X-band data. As a result there are three or four days per year during which the TGS is unable to receive data because of snow and ice accumulation on the reflector. Reception is impaired or impossible not only because of the added load to the servo drives but more importantly because the ice build up defocuses the antenna. Installation of heaters bonded to the reflector at this time is not feasible because disassembly and sandblasting of the reflector would be required and the procedure would be very expensive. Etheylene Glycol anti freeze solution would solve the problem but is not recommended for environmental reasons. The only other solution is flowing heated air onto the reflector exercising care such that the reflector contour is not thermally distorted. This approach has not been implemented as a trade off between cost and the amount of lost data does not appear to warrant it at this time.

6) The antenna feed is protected with a radome; the feed and associated RF components are pressurized to prevent moisture build up; a dry air compressor automatically maintains system pressure. Low pressure is indicated by an alarm light. For unknown reasons, the radome developed a crack allowing rain water to accumulate in the feed. Unfortunately, the accumulated water in the feed exceeded the air pressure head such that the low pressure alarm was not activated. The lesson learned is that the low pressure sensor should have been located in the feed rather than down stream from the feed.

7) During the operational readiness check-out of the TGS prior to the Landsat 5 launch it was found that there were a considerable number of problems and that system performance was substandard. A number of the problems were in the X-band system which had not been used since the failure of the X-band frequency source on Landsat 4. Other problems were masked by the system design margins which permitted usable data to be acquired even though performance was degraded. This situation resulted from operation of the system by contractor personnel not fully trained in system maintenance and test. The lesson is that sophisticated equipment, even though designed to be fault tolerant and provided with redundancy to maximize availability, requires trained skilled maintainers. The system was restored to full operational capability utilizing the built-in test equipment capability, and required maintenance was performed and demonstrated to the contractor personnel.

System performance of the TGS with regard to data analyzed from Landsat 4 and compared to that received from Landsat 4 was virtually identical, demonstrating the integrity of the spacecraft to ground station performance.

6.11.3 SOFTWARE DEVELOPEMENT

Software is a new field compared to hardware and, as such, does not have the extensive history of hardware design and development methods. On Landsat 4, proper emphasis was not given to software developement and methods early in the program.

a. Coding was initiated prior to completion and review of system requirements definitions. This led to false starts and continuing revision as the system requirements became firmer. The lesson learned here: premature coding is expensive; wait until reasonably firm system requirements are available.

b. Development of metric for performance is essential if progress is to be controlled. There must be known measurement points in the software development program and planned versus actual charts must be kept. Realistic performance goals are essential to track the effort. Updating mission requirements often requires replanning, that in turn may mask impending problems. A thorough management plan is essential; coding and testing standards must be set up and followed.

c. Software turnover control: there should be phased software turnover at specific points in the program, from the smallest functional and lowest level of documentation through the entire system performance and test program. Systems Engineering is important throughout the turnover control to provide the facility viewpoint and to input and upgrade the interfaces and requirements as the effort progresses. Uniform development among the facilities is desirable so that suitable coordination can be obtained; i.e., if a facility is completed early, don't overwhelm it if other portions of the system are in trouble.

d. The structural programming concepts based on the GE SEAM Manual used for Landsat software development were successful in ensuring that the development process met the schedule and the resulting code was maintainable. Changes/modifications to programs were easily isolated and identification of all affected modules easily performed.

e. Carryover of software from earlier projects was, in general, not successful, due to different development personnel and different computers used.

f. The unified organization of system programmers forced commonality into hardware driver development and system architectures.

g. The rigid coding standards employed in the software development phase made maintenance easier. Due to these standards, tools to analyze source code (for configuration management, lines of code counts, data dictionary development, etc.) were automated, which resulted in precise and accurate information system support services.

h. The use of pre-programmed sets of standard in-line comments (e.g., prologues) and executable code (e.g., standard error handling) led to software module "skeletons" that greatly reduced the amount of coding needed to develop a piece of software.

i. DRRTS software subcontractor work was not closely monitored and resulted in:

   1) Software breakage
   2) Necessity to redesign completely the directory generation software

j. The complexity of the functions and interfaces of the MSS control and communication software, as well as the monitor software for individual packages, were underestimated. This resulted in a significant increase in the effort in software development and testing.

k. The software development cycle was started before the system level requirements were fully established, resulting in substantial software breakage. For example, the entire MAG package developed up to Build No. 1 was discarded after the rebaseline. All software developed by TRW was also discarded.

l. The importance of comprehensive reporting capability was recognized and provided for. As instrument and process performance became better understood, the system reporting capability also evolved so that now, detailed statistics on every key aspect of system performance can be routinely provided.

6.11.4 TEST

a. The importance of test data cannot be overemphasized. Time and effort in acquiring or constructing test data is well spent, the best test data being actual, acquired data.

b. The use of a functional test philosophy, i.e., test plans and procedures structured to validate major functions, was a valid concept.

c. There is a need to plan and develop a set of coordinated test data. The data is needed for testing during the various phases of implementation, integration, operation and maintenance.

d. Easily accessible local simulators and files of test data sets should be available. This should be used for exercising local hardware and software systems realistically, especially with regard to data content and data rates.

e. Integration is similar to implementation, but the test data should be more realistic and less specialized. The final stages of integration must include system testing with all the external interfaces.

f. The development and use of comprehensive diagnostics and line tests to verify system integrity is invaluable when product quality cannot be accurately assessed until well after the fact, as is the case with MIPS and TIPS.

g. Because of the extreme complexity of the TIPS special purpose hardware, numerous device diagnostics and built-in test capabilities were provided. With operational experience this capability has been improved and expanded to provide more meaningful process and device diagnostics.

h. A Flight Segment simulator that will respond to commands and generate realistic telemetry test data is needed to allow the Flight Segment Controllers to "operate" the observatory. An effective, real-time simulation well before launch is desirable. This should include activation and normal orbital operations. In several instances, early in the program, commanding via GSTDN could not be completed during a pass. Since the Landsat Flight Segment was designed to be "safe", no anomalies could be attributed to the lack of adequate simulations and rehearsals. It was annoying at times, however, when LOS occurred before the scheduled routine.

i. Simulators and displays can be used to test maintenance of hardware and software systems.

j. Unit testing of software fixes is not sufficient. Often, a new problem is introduced by the software "fix" that is not discovered until later in the data processing flow.

k. Independent test teams working under an organization separate from the software development organization provide an unbiased critique of the functionality of the software product as a byproduct of testing. However, a decision to use such teams must also consider the substantially increased costs and prolonged schedules.

l. Early involvement of operations personnel in the testing of the system provides valuable feedback on the operability of the system, so that adjustments can be made prior to the operational timeframe.

m. Although adequate inspection procedures were finally achieved in the CCT PROFILE program, for the non-video aspects of CCTs, video inspection was conspicuously absent. A presumption of acceptable video quality was made if the same image was satisfactory in the 241 mm film and the P- or A-tape from which the CCT was produced. Since the CCTs were made from ingests different from those that produced the 241 mm film, the presumption of quality is therefore unreliable. This situation could be avoided by allowing the same ingest to produce both 241 mm film and CCTs.

n. The independent test team concept for MIPS integration and testing resulted in lack of communication between system and software engineering groups. This increased the I&T effort and made verification of requirements difficult.

6.11.5 OPERATIONS

a. The concept of "equivalencing" the amount of operations resources needed to service a special request to the number of products generated in the same timeframe permitted evaluating the "cost effectiveness of implementing the special request, giving each the priority deserved and even eliminating the least productive.

b. Installation of parameter changes in a production support environment prior to population to operations significantly reduced the number of erroneous data values in operational parameter files.

c. A need to modify some aspects of the TM R&D activity was dictated by operational experience and actual instrument and ground processing performance. The R&D period also pointed out several deficiencies in the TIPS design. As an example, the current design does not allow the implementation of scan level radiometric corrections.

d. Operational experience has identified deficiencies in process control and data management, particularly in the area of error handling, that are continually being refined to improve the system's operational efficiency.

6.11.6 QUALITY ASSURANCE

a. It is believed that an unduly low priority was tacitly assigned to Quality Assurance, causing time loss by the backtracking that this made necessary.

b. In addition, there was an underestimation of the time and resources needed to perform adequate Quality Assurance. As a result, troublesome problems arose with the external customer - the EROS Data Center, Sioux Falls, S.D., of the Department of the Interior. Considerable unforeseen time and effort were expended, to the detriment of production, in order to standardize the tolerances, measuring equipment and test techniques. For film processing problems it even became necessary to engage an external consulting contractor.

c. No software was developed to permit ready cross-references among scene IDs, R-tape IDs, A-tape IDs, P-tape IDs, CCT IDs and film roll IDs. As a result, defect investigations required laborious alternate manual techniques resulting in substantial loss of man-hours.

d. Inadequate physical facilities were provided for the orderly storage, retrieval and inspection of computer printouts and film rolls resulting in further lost time.

c. The Quality Assurance Group could have enhanced defect investigations if an early display had been developed to show the history and statistics of all defects observed.

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APPENDIX A

BIBLIOGRAPHY OF LANDSAT GROUND SEGMENT PUBLICATIONS

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   TAG Data for Forecasting Video Defects in 241 mm Film
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SVS 9831	28-Track High Density Tape Recorder	LAS,IGF	C	2/15/83	T. Aslam
SVS 9832	Laser Beam Recorder (LBR)	TIPS	J	8/30/84	R. Spencer
SVS 9833	Transportable Ground System (TGS)	TGS	A	10/16/81	P. Mellusi
SVS 9834	Federation of Functional Processors	TIPS	C	3/7/83	R. Spencer

* See Legend.

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GES 9844	Item Dev. Spec for FSS of LSD CSF	CSF	D	12/18/81	M. Elgin-Smith
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GES 10091	Ground Segment/NASA Project Office ICD	GND	0	10/23/81	T. Horn
LSD-ICD-001	NASA Document			05/23/83	
GES 10093	CSF/MMF-M ICD	GND	K	12/14/82	M. Elgin-Smith
GES 10094	Ground Segment S/W Documentation Plan	GND	0	08/23/82	D. Miller
GES 10096	Data Formatter Processor	TIPS	B	06/15/82	R. Spencer

NO.	TITLE	FACILITY	ISS/REV	DATE	RESPONSIBLE
GES 10098	TGS Software	TGS	A	08/07/81	R. Stiegler
GES 10099	Ground Segment Software QA Plan	GND	B	06/24/82	J. Szabo
GES 10102	MMF-M H/W S/S Spec	MMF	A	10/02/81	K. Thom
GES 10103	Operational QA Plan	GND			P. Kiss/ F. Kabat
GES 10105	GS S/W Mgmt. Plan	GND	0	08/18/82	D. Miller
GES 10106	Support Services Sub system (SSS)	CSF	A	12/18/81	N. Thurston
GES 10108	Ground Segment Design Description Document	GND	A	07/31/81	M. Friedlander
GES 10109	S/W Engineering Methodology	GND	0	09/14/82	S. Hannan
GES 10110	Frequency Synthesizer Unit (FSU)	IGF	B	10/30/81	T. Aslam
GES 10111	Nascom I/F H/W	CSF	A	02/27/81	K. Thom
GES 10113	Programming Practices Standards & Conventions	GND	0	09/21/81	D. Miller
GES 10114	LSD Ground Segment Grounding	GND	C	06/09/82	G. Condon
GES 10115	Ground Segment/NCC ICD	GND	C	06/23/83	B. Nims
GES 10116	Network Control Center	GND	C	05/06/82	B. Nims
SVS 10122	DFCB #1, Data Acq. Plan	GND	0	08/28/81	A. Kitto
SVS 10123	DFCB #2, Telemetry	GND	0(AN-01-02)	12/18/81	A. Kitto
SVS 10124	DFCB #3, Command	GND	0	09/25/81	A. Kitto
SVS 10125	DFCB #4, GPS	GND	0	08/28/81	A. Kitto
SVS 10126	DFCB #5, Payload	GND	0(AN01)	12/11/81	A. Kitto
SVS 10127	DFCB #6, Products	GND	0	07/31/81	F. Kabat

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NO.	TITLE	FACILITY	ISS/REV	DATE	RESPONSIBLE
GES 10134	Ground Segment/NOAA ICD	GND	A	11/20/81	T. Horn
GES 10135	Landsat-D Safety Design Plan	GND	0	03/03/79	P. Ruggles
GES 10140	Ground Segment/Orbit Comp Group (GS/OCG) ICD	GND	B	06/21/82	T. Horn
GES 10142	GS to Photo/Shipping Support ICD	GND	C	07/26/82	T. Horn
GES 10143	Ground Segment/Networks ICD	GND	A	09/05/84	T. Horn
GES 10154	Standard Peripheral I/F Vol. 2 added	LAS,IGF	C	06/07/82	L. Woolley
SVS 10261	Flight Segment to Ground Segment ICD	FS/GS			R. Clayton
GES 10483	241 mm High Resolution TM Film AT	IGF	A	02/24/83	H. Ahmed
GES 10484	MMF-TM	MMF	C	09/05/84	R. Brown
GES 10485	GS to Bldg. 23 (DIF) ICD	GS	0	07/26/82	T. Horn
GES 10486	MMF-M/MMF-T ICD	MMF	B	02/15/83	M. Elgin-Smith
GES 10487	Item Development Spec for Interim TM Data System	MMF	A	09/15/83	D. Abbott
GES 10489	MMF-T/TIPS ICD	MMF,IGF	L	06/18/84	E. Hogan
GES 10490	Appendix D (TM-CCT) Vol. VI, Products DFCB		J	05/08/84	
GES 10491	Thematic Mapper Image Proc. Syst. Algorithm Control Book		D	03/26/84	V. Karkhanis

LEGEND:

0 =	Initial Issue
A, B =	Revision Number
(AN) =	Alteration Notice
-(C,D,L,M,T) =	Multiple Use Document Identification
	C = CSF
	D = DRRTS
	L = LAS
	M = MIPS
	T = TIPS

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APPENDIX B

ACRONYMS

A	Additive
A-Tape	HDT-A, radiometrically corrected, high density archival tape
AC	Alternating Current
ACCA	Automatic Cloud Cover Assessment
ACS	Attitude Control System
ADP	Automatic Data Processing
ADPE	Automatic Data Processing Equipment
ADDS	Applications Data Development System (Scrounge)
ADS	Angular Displacement Sensor
AGC	Automatic Gain Control
ANDP	Ancillary Data Calculation Process
AOS	Acquisition of Signal
AP	Array Processor
APCS	Accelerated Payload Correction Subsystem
AROT	Acquisition Requirements Order Tape
ASCII	American Standard Code for Information Interchange
ASIT	Acquisition Status Information Tape
ATTN	Attention Processor (TIPS Software)
BIL	Band Interleaved by Line
BIP	Band Interleaved by Pixel
BPI	Bits per Inch
BSQ	Band Sequential
CALC	TAG Calculations
CCA	Cloud Cover Assessment
CCP	Cloud Cover Assessment Process
CCT	Computer Compatible Tape
CCT-A	CCT Containing Partially-Corrected Data
CCT-AM	Partially Processed CCT for MSS Data
CCT-AT	CCT Containing Partially-Corrected TM Sensor Data

CCT-P	CCT Containing Fully-Corrected Data
CCT-PT	CCT Containing Fully-Corrected TM Sensor Data
C&DH	Communication and Data Handling
COBOL	Common Business Oriented Language
COIL	CSF Operator Interface Language
CODASYL	Conference on Data Systems Language
Comtal	Trademark of Online Display Device
CP	Control Point
CPC	Control Point Chip
CPD	Control Point Directory
CPL	Control Point Library
CPLB	Control Point Directory Build
CPMS	Cost Performance Measurement System
CPN	Control Point Neighborhood
CPU	Central Processing Unit
CRT	Cathode Ray Tube
CSF	Control and Simulation Facility
DAS	Data Base Administration Subsystem
DBA	Data Base Administrator
DBSTAT	Production Area Status Modification Utility
DBMS	Data Base Management System
DBMS-10	DEC-10 System Software for Data Base Management
DBMS-20	DEC-20 System Software for Data Base Management
DCL	Digital Command Language
DDP	Digital Data Processor
DEC	Digital Equipment Corporation
DECnet	Digital Equipment Corporation Communications Network
DFP	Data Formatter Processor
DMA	Direct Memory Access
DML	Data Management Language (see GARDEN)
DMS	Data Management System
DR11B	DEC Unibus DMA Interface Device
DRRTS	Data Receive, Record and Transmit System

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DSM	Downlink Synchronization Module
DXFP	Data Extraction and Formatting Process
EDC	EROS Data Center
EROS	Earth Resources Observation System
ESR	Equipment Service Report
EWO	Engineering Work Order
FET	Field Effect Transistor
FFP	Federation of Functional Processors
FMS	Flight Segment Management Subsystem
FO	Flight Operations
FOS	Flight Operations Subsystem
FOV	Field-of-View
FPS	Floating Point Systems Inc.
FS	Flight Segment
FSS	Flight Scheduling Subsystem
FSW	Flight Software
F70-AM	70 mm Latent Film of Partially Processed MSS Data
F70-AT	70 mm Latent Film of Archival TM Data
F241-AM	241 mm Latent Film of Partially Processed MSS Data
F241-PM	241 mm Latent Film of Fully Processed MSS Data
F241-PT	241 mm Latent Film of Fully Processed TM Data
F241-AT	241 mm Latent Film of Archival TM Data
F/S	Flight Segment
GARDEN	Data Manipulation Language
GCDG	Geodetic Correction Data Generation
GCM	Geometric Correction Matrix
GCO	Geometric Correction Operator
GCP	Geodetic Control Point
GE	General Electric Company
GECP	Geometric Correction Process
GES	Ground Electronic Specification

GFE	Government Furnished Equipment
GHIT	Goddard HDT Inventory Tape
GHIT-AM	Inventory Tape for Partially Processed MSS Data
GHIT-AT	Inventory Tape for Partially Processed TM Data
GHIT-PT	Inventory Tape for Fully Processed TM Data
GMP	Geometric Correction Matrix Calculation Process
GMS	Ground Segment Management Subsystem
GPS	Global Positioning System
GS	Ground Segment
G/T	Ratio of Gain to Systems Noise Temperature
GSFC	Goddard Space Flight Center
GSTDN	Ground Spaceflight Tracking and Data Network
GSIT	Ground Segment Integrated Test
HARVEST	Query Language
HCS	HDDR Control Software
HDDR	High Density Digital Recorder
HDDT	High Density Digital Tape
HDT	High Density Tape
HDT-A	HDT-Archive Format (Partially Corrected)
HDT-AM	HDT-A for MSS Instrument Data
HDT-AT	HDT-A for TM Instrument Data, corrected radiometrically
HDT-PT	HDT for TM Instrument Data, fully corrected
HSI	High Speed Interface
ICD	Interface Control Document
IDT	Industrial Data Terminal Corporation
IFOV	Instantaneous Field-of-View
IGF	Image Generation Facility
IMS	Information Management Subsystem
IMSFCC	Information Management Subsystem FFP Control Computer
IPS	Image Processing System
IPSC	IPS Computer
I^2RV	Inter-Range Vector Data

IQL	Interactive Query Language
IRIG	Inter-Range Instrumentation Group Time Code
IRIG-A	IRIG Time Code Series A
ITDS	Interim TM Data System
LAS	Landsat-D Assessment System
LBP	Library Build Process
LBR	Laser Beam Recorder
LOS	Loss of Signal
LNA	Low Noise Amplifier
M	Multiplicative
MAG	MSS Archival Product Generation
MCCA	Manual Cloud Cover Assessment
MDKIO	MSS disk
M&A	Multiplicative and Additive
MENU	Control Processor, User Friendly
MIPS	MSS Image Processing System
MIVT	Major Item Verification Test
MNF	Minor Frame
MOR	Mission Operations Room
MPT	Mission Planning Terminal
MSCD	Mirror Scan/Sweep Correction Data
MSS	Multispectral Scanner
NASA	National Aeronautics and Space Administration
NASCOM	NASA Communications Network
NBTR	Narrow Band Tape Recorder
NCC	Network Control Center
NCCS	Network Control Center Subsystem
NIF	Nascom Interface Facility
NOAA	National Oceanic and Atmospheric Administration
NOCC	Network Operations Control Center
NRZ	Non-Return to Zero

NRZI	Non-Return to Zero Incrementing
NRZ-L	Non-Return to Zero Level
NRZ-M	Non-Return to Zero Mark
NTTF	Network Test and Training Facility
OBC	Onboard Computer
OCC	Operations Control Center
ODP	Online Display Process
ORVT	Operational Readiness Verification Test
P-Tape	HDT-P Fully Processed, High Density Tape
PCL	Prime Compressed Low Mode
PCH	Prime Compressed High Mode
PCD	Payload Correction Data
PCS	Payload Correction Subsystem
PDF	Programmable Data Formatter
PDP	Peripheral Data Product
PDR	Problem/Defect Report
PE	Performance Evaluation
PEPG	Performance Evaluation Product Generation
PES	Performance Evaluation Subsystem
PGP	Product Generation Process
PGS	Product Generation Subsystem
PLL	Prime, Linear, Low Modes
PM/FL	Performance Monitor/Fault Location
POCC	Payload Operations Control Center
PR	Process Request
PSDO	Parallel-to-Serial Data Output Device
QA	Quality Assurance
QAF	Quality Assurance Film
QFP	Quality Assurance Film Generation Process
QIO	Queue Input/Output
QLM	Quick-Look Monitor Unit

Rmax	Maximum Radiance Value
Rmin	Minimum Radiance Value
R-Tape	(HDT-R) High Density Uncorrected Raw Tape
RCFP	Radiometric Correction Function Calculation Process
R&D	Research and Development
RDCP	Radiometric Corrected Process
RDE	Recursive Distortion Estimator
RFP	Request for Proposal
RLUT	Radiometric Look Up Tables
RP06	DEC 176 MB Disk or Removable Disk Storage Unit
RP07	DEC 283 MB Disk
RQI	Radiometric Quality Indicator
RSS	Request Support Subsystem
RSX-11M	Multi-Tasking Operating System Software
SA	Scientific Atlanta
SC	Signal Conditioning
SCC	Scene Content Correction
SCD	Systematic Correction Data
SCROUNGE	Applications Data Development System
SCT	System Control Terminal
SEED	Data Base
SCDG	Systematic Correction Data Generation
SMB	System Memory Bus
SPDI	Serial-to-Parallel Data Input Device
SPI	Special Peripheral Interface
SPROUT	Transaction Processor
STC	System Test Console
STOL	System Test and Operations Language
STR	System Test Review
SU	Switching Unit

TAC	Telemetry and Command
TAG	TM Archival Product Generation
TAS	Tape Archives Subsystem
TCL	TM Control Point Library Build Package
TDQ	TM Data Quality Assessment Package
TDRS	Tracking and Data Relay Satellite
TDRSS	Tracking and Data Relay Satellite System
TEP	Telemetry Extraction Process
TFG	TM Final Product Generation
TGS	Transportable Ground Station
TIG	TM Initial Product Generation Package
TIPS	TM Image Processing System
TM	Thematic Mapper
TMAS	TM Archiving Subsystem
TPC	TM Payload Correction System
TQF	TM Quality Assurance Film Generation Package
TRW	TRW Defense and Space Systems Group
TSIM	Test and Simulation Subsystem
VAX 11/780	Virtual Address Extension DEC Model Computer 11/780
VT	Video Terminal
VT78	Intelligent CRT Terminal
VT100	Non-Intelligent CRT Terminal
WRS	World Reference System, locating all scene centers